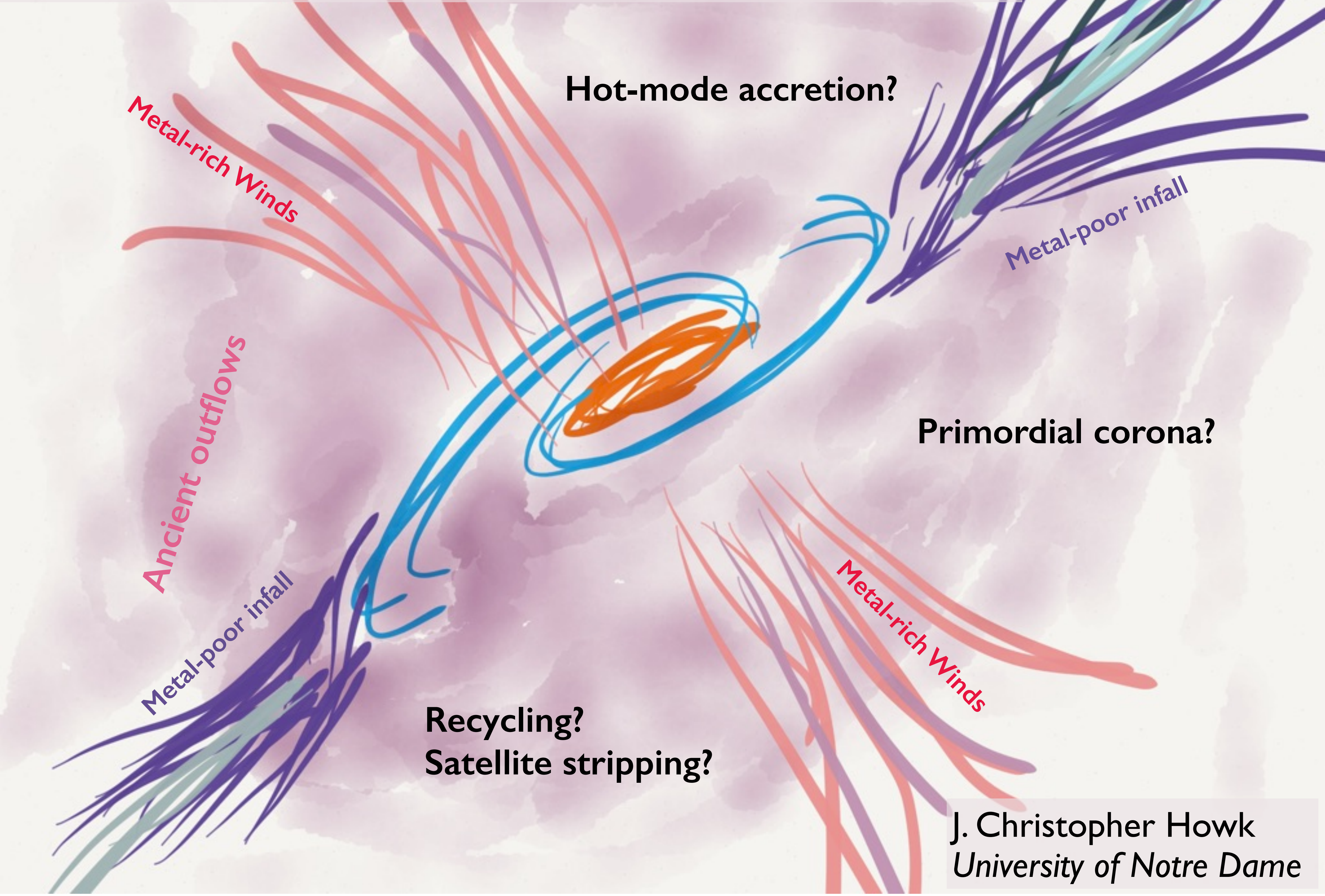
The CGM plays a fundamental role in and potentially provides unique constraints on galaxy evolution.



J. Christopher Howk
University of Notre Dame

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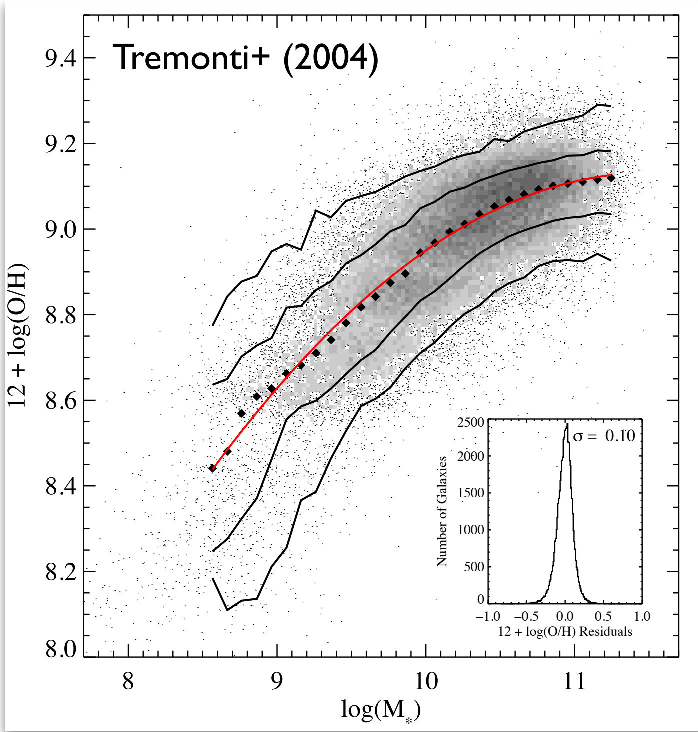
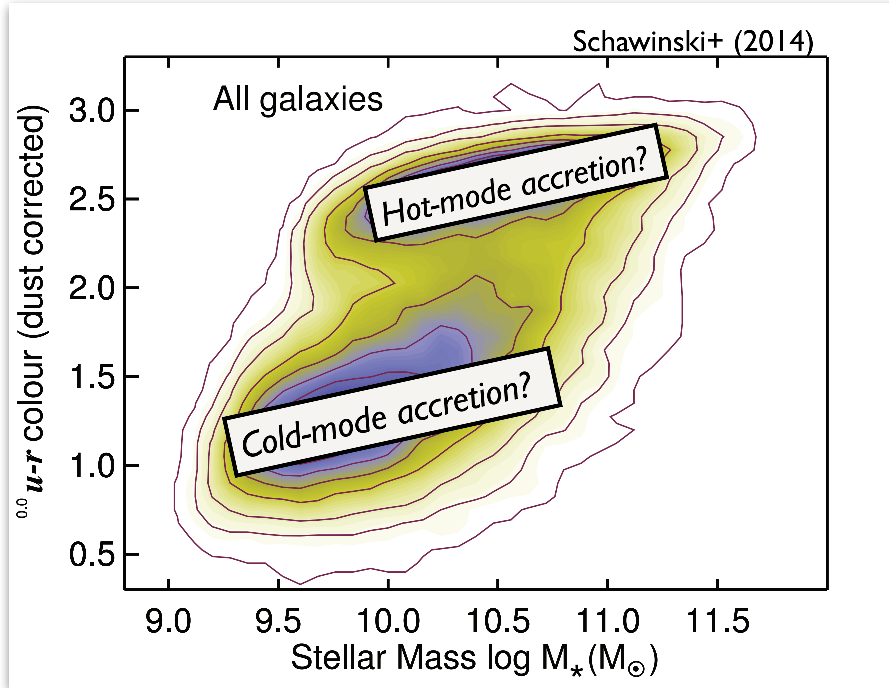
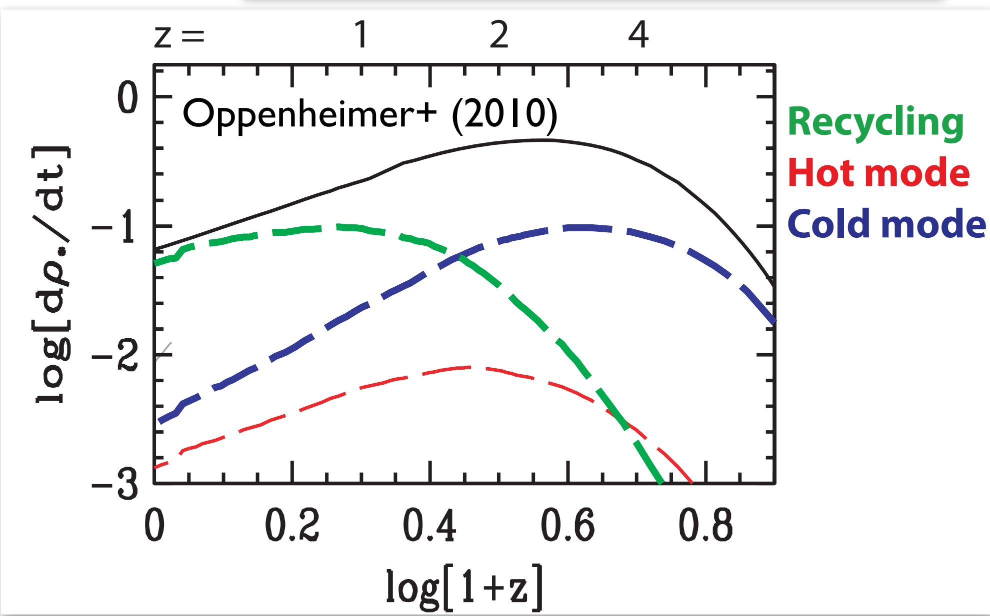
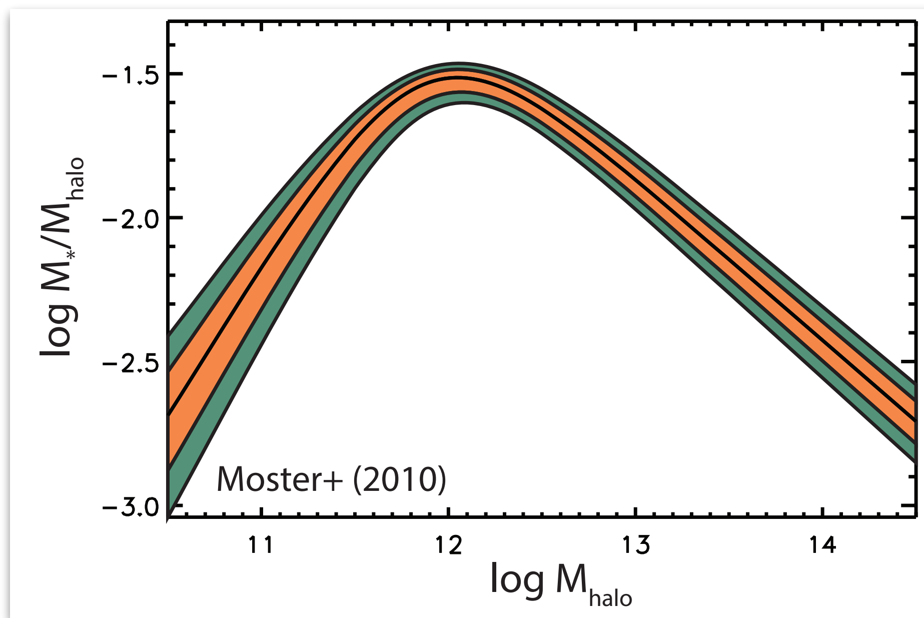
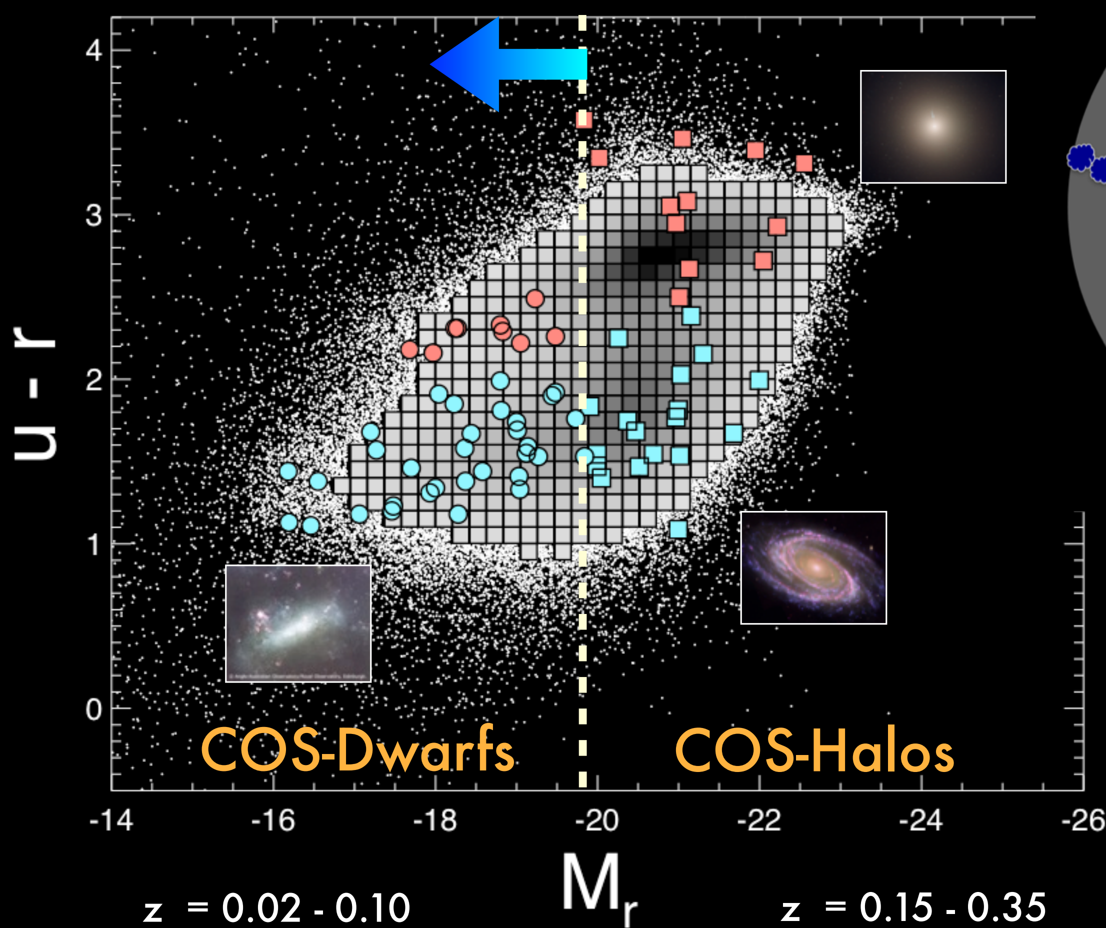


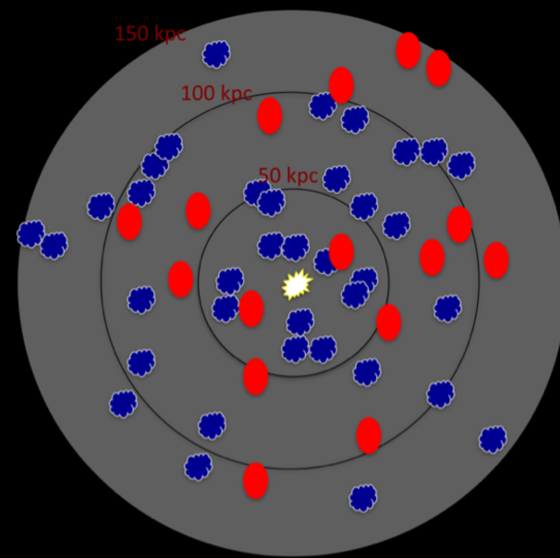






COS-Halos survey to study CGM vs. galaxy properties



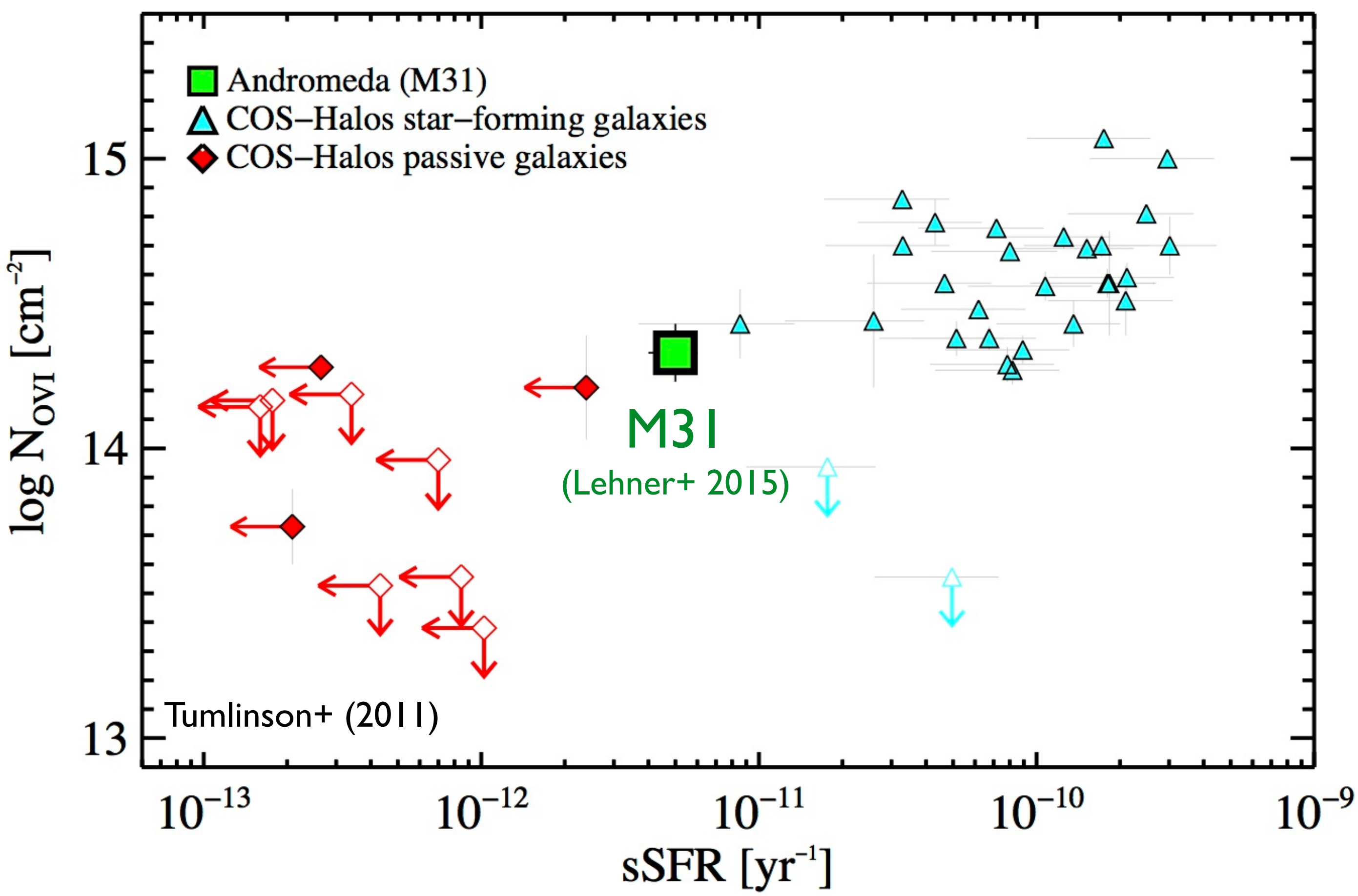


z = 0.02 - 0.10
logM* = 8 - 10
optimal for CIV

z = 0.15 - 0.35
logM* = 10 - 11.5
optimal for OVI

ALL GALAXIES SELECTED PRIOR TO ABSORPTION

COS-Halos: warm metals in CGM associated with star formation.



The presence and quantity of "warm" metals is strongly correlated with star formation properties of galaxies.

…but it is not for H I (Thom+ 2012).

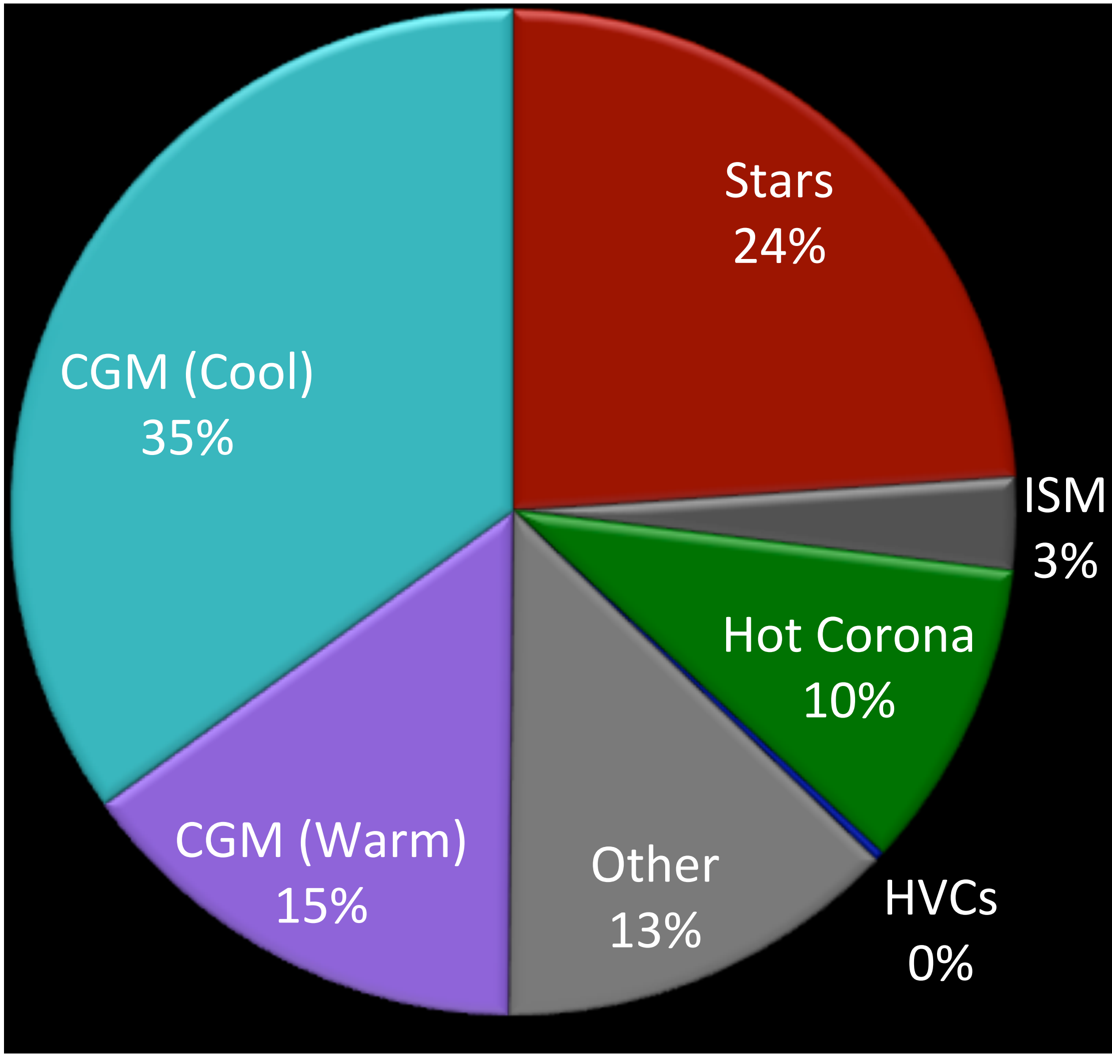
The CGM harbors a large fraction of galactic baryons

Cool+Warm CGM mass budget:

Typical mass of cool gas in CGM:
$M_{\text{Cool CGM}} \sim 6 \times 10^{10}\ M_{\odot}$

Typical mass of warm gas in CGM:
$M_{\text{Warm CGM}} \sim 2 \times 10^{10}\ M_{\odot}$

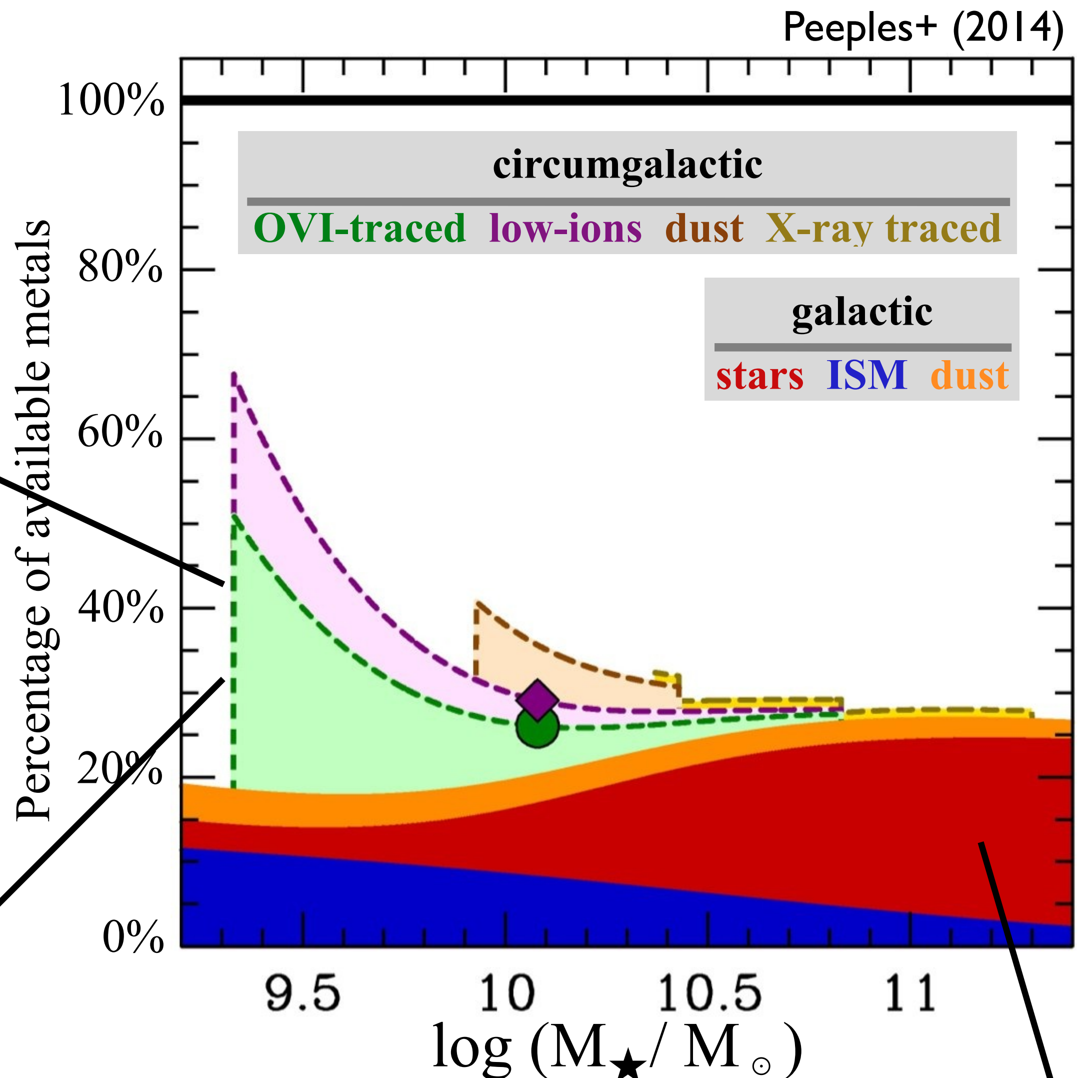
There may not be a galactic "missing baryons problem."



Werk+ (2014); also Stock+ (2013), Lehner+ (2015),

The CGM harbors as many metals as stars in galaxies.

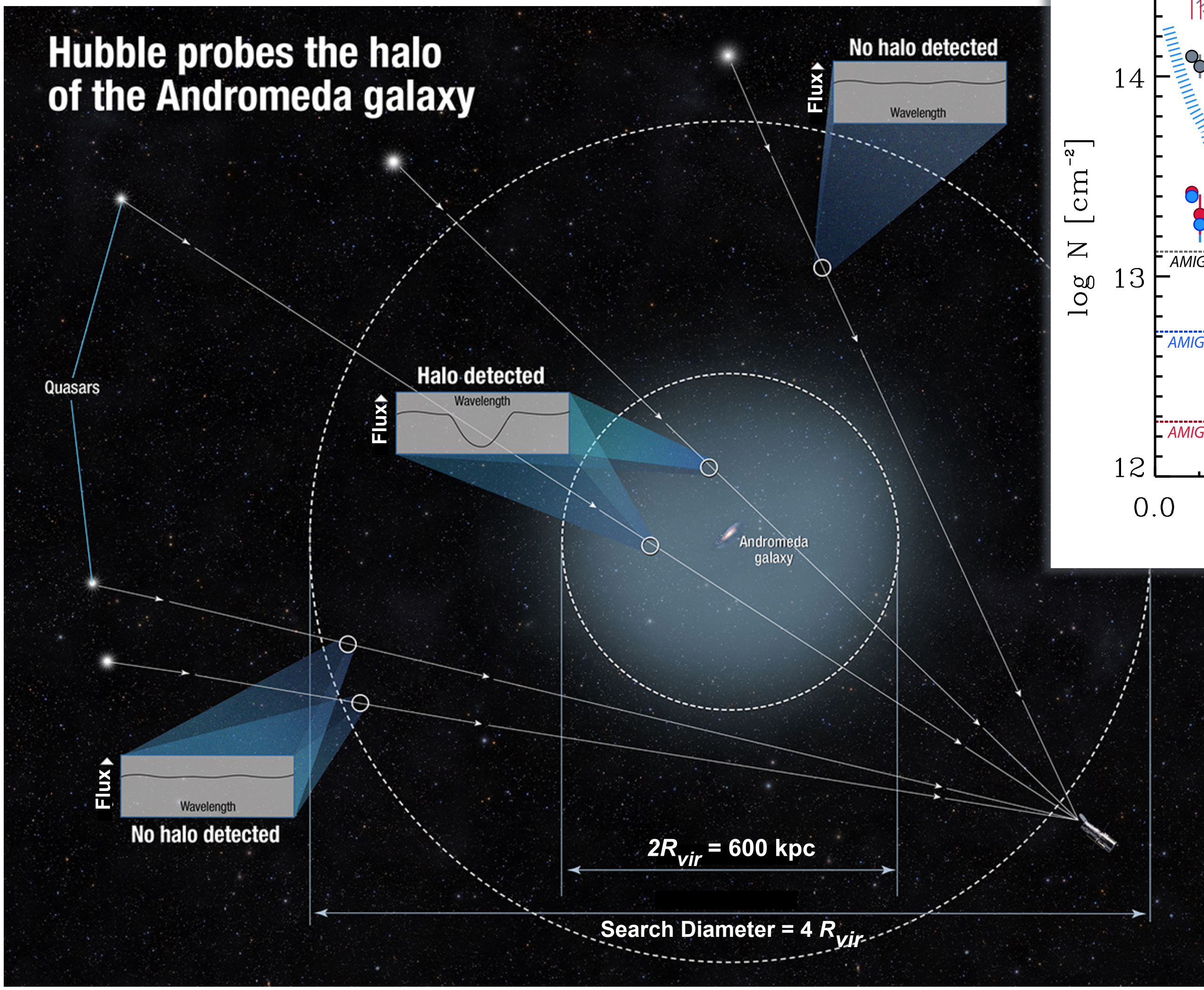
>40% of all metals made in a galaxy are easily identified.

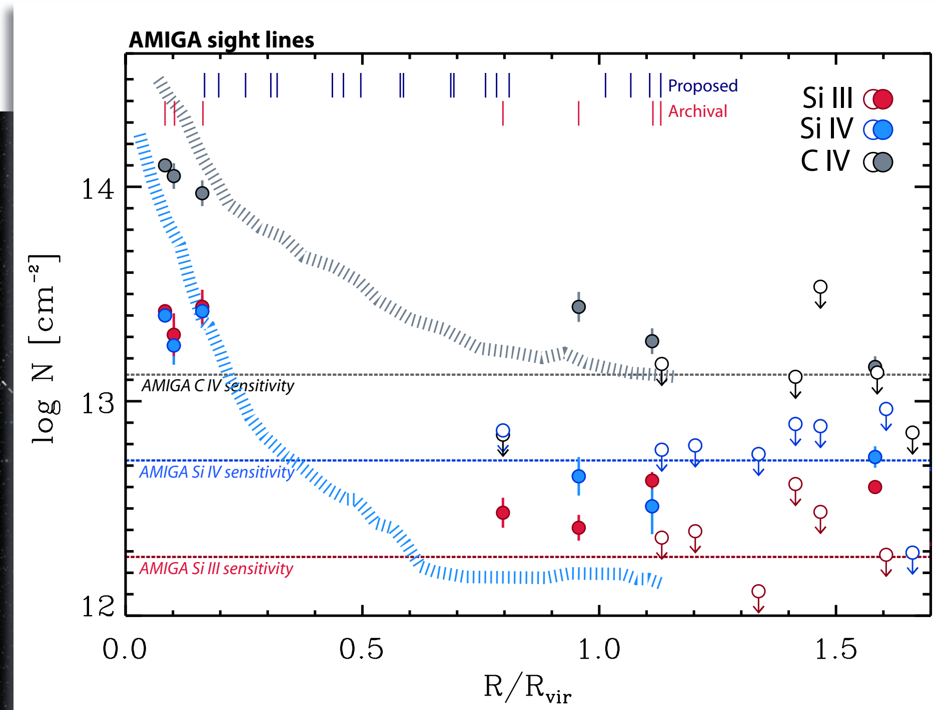


There are as many metals present in the CGM as in stars in galaxies.

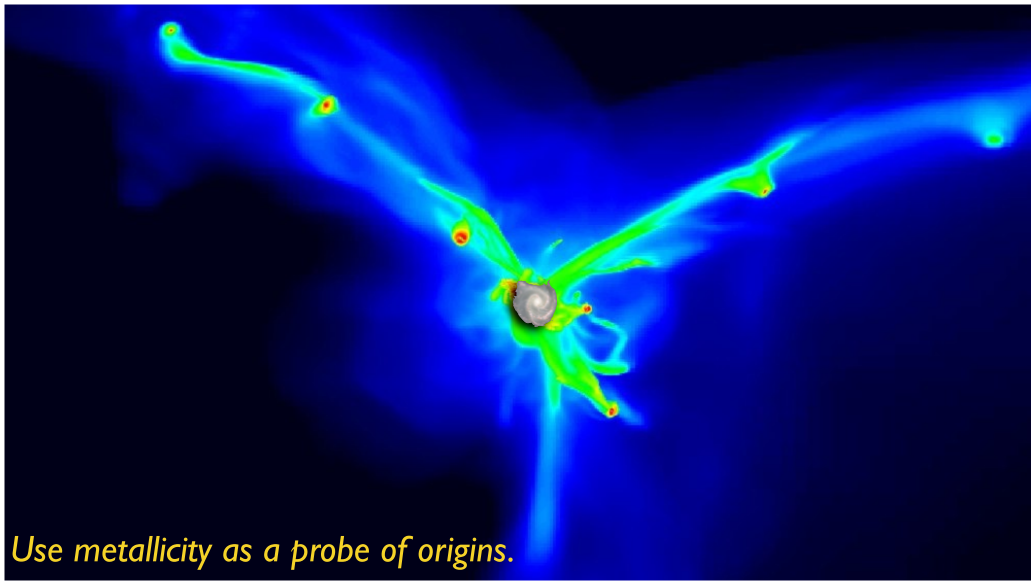
Stars+ISM+dust = 20%

The CGM harbors a large fraction of galactic baryons



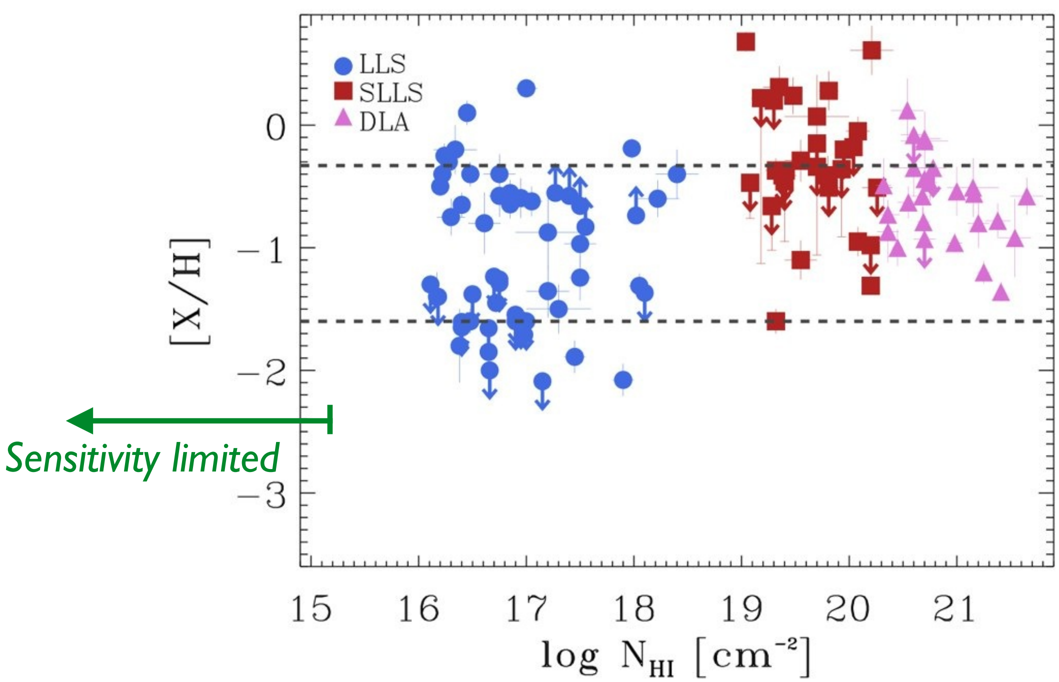


We want to dissect the CGM of galaxies, learning about each component.



A. Dekel

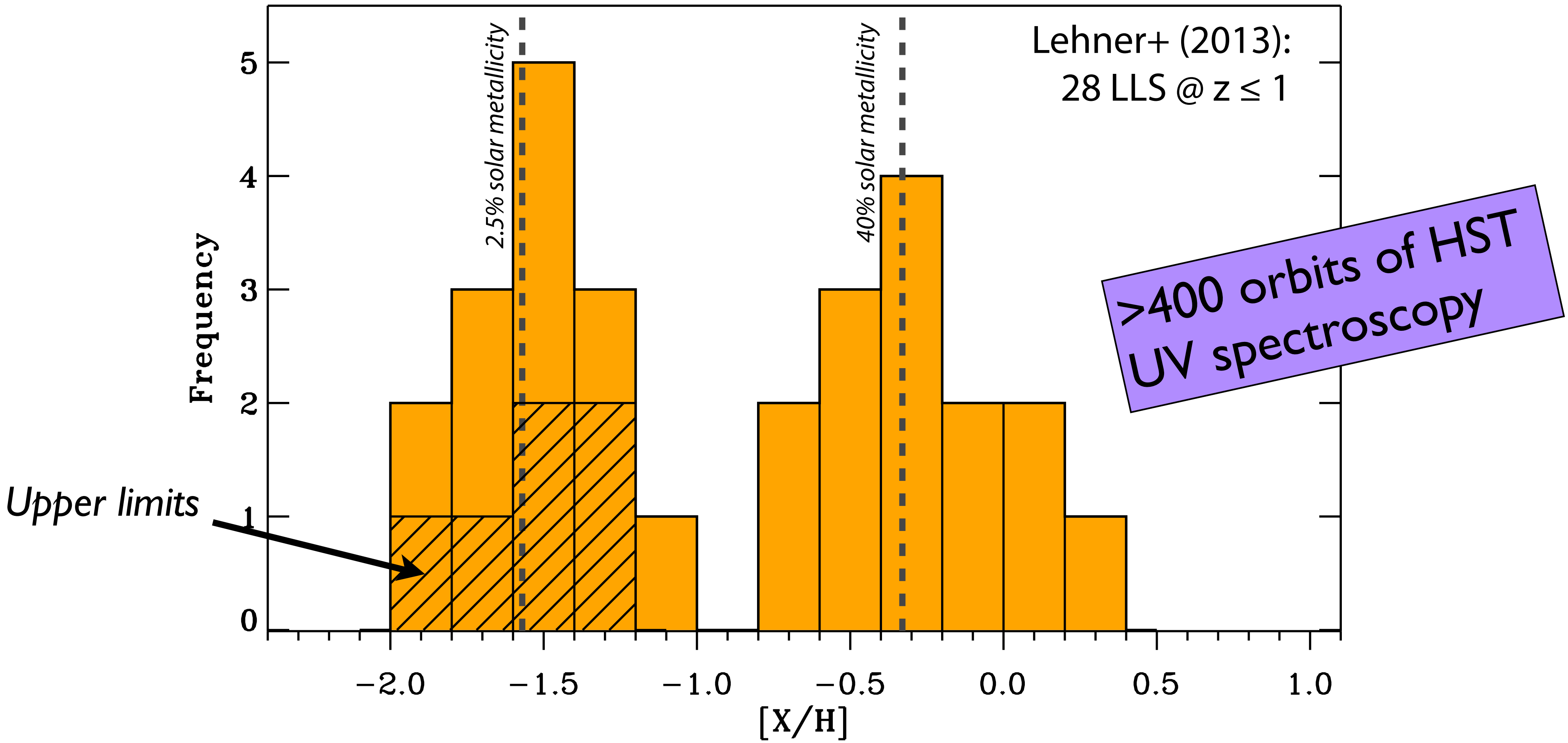
We'd like to make a map of the CGM and tag the gas by its origins.



The best we can do now is study the **metallicity** (origins) of the gas as a function of **column density** (~location).

Lyman limit systems probe infall and outflows at low-z.

Metallicity distribution of z ≤ 1.0 Lyman limit systems
[16.1 ≤ log N(H I) ≤ 18.5]



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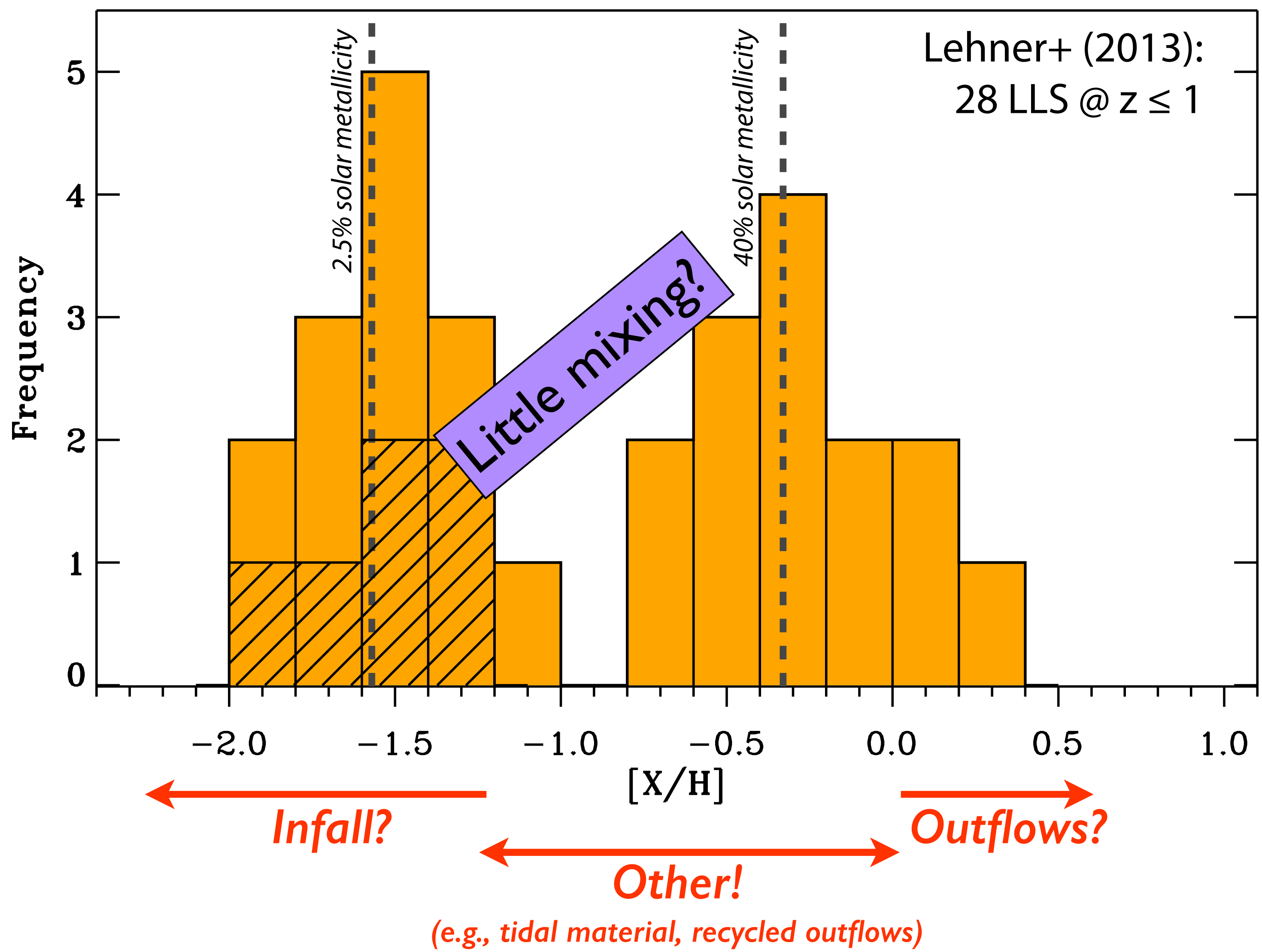
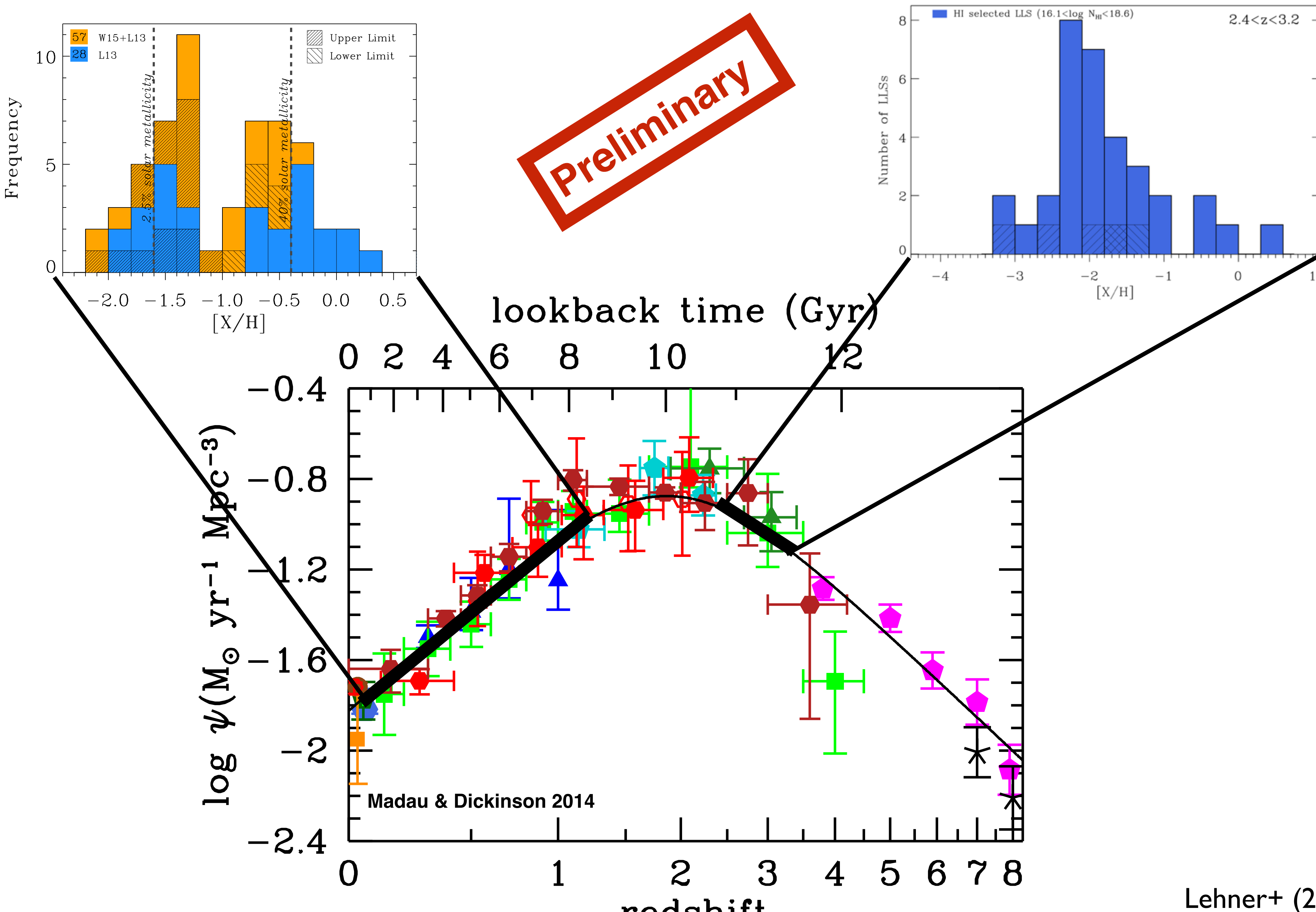


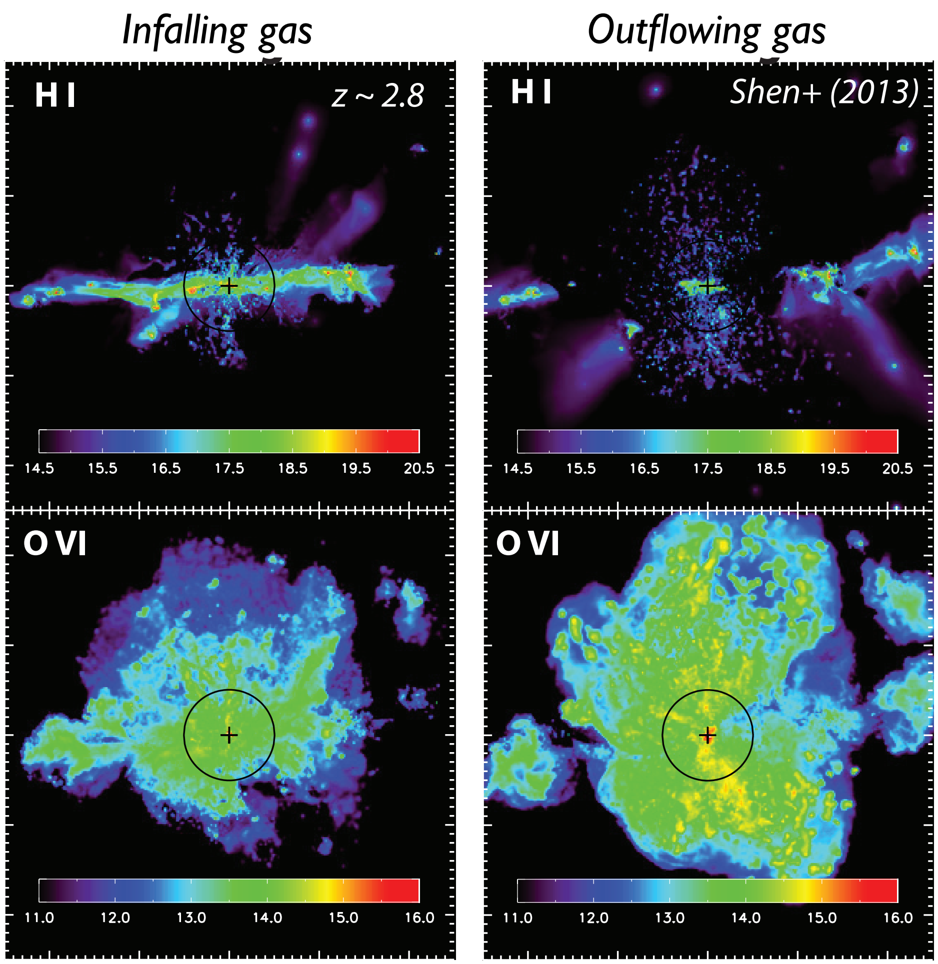
Lehner+ (2013)

How does the MDF of the LLSs/CGM evolve with z?



Lehner+ (2015)

The future: mapping the origins of the CGM gas



Higher ionization states more directly probe the driving fluid, the more diffuse CGM.

1) We want to **map** the CGM as a function of ***ionization state*** and ***metallicity***.

This means:

– Developing better statistical maps of the CGM with galaxy properties, etc. (ala COS-Halos).

– Directly mapping absorption lines toward many sight lines in individual galaxies, headed toward tomography. (Not even done yet for M31.)

– Observing resolved galaxies at low redshift to connect to H I mapping. *(21-cm won't get <few x 10^{17} cm^{-2}.)*

– Emission line imaging.

Critical capabilities:

– Large aperture (sensitivity).

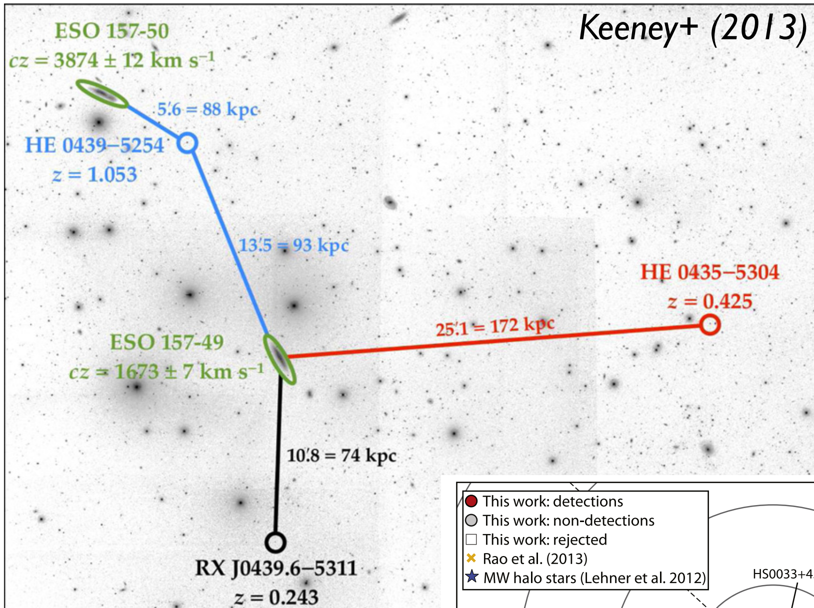
– High resolution (R>20,000).

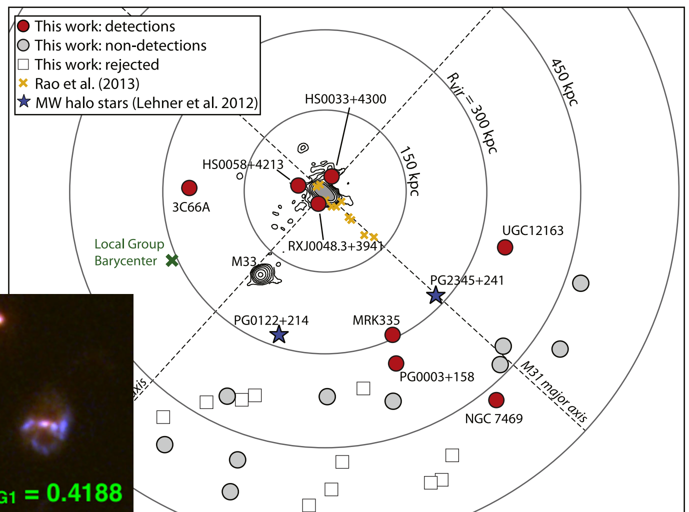
– FUV capability to ~1000 Å.

– Efficient NUV capabilities to 3000 Å (Lyα).

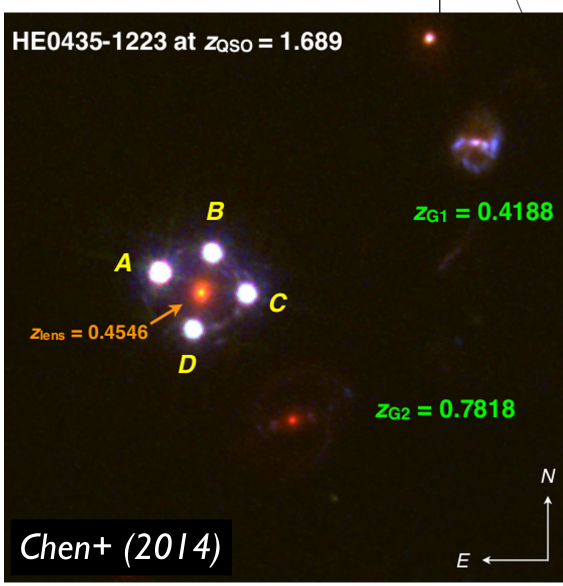
– …or UV imaging sensitivity, perhaps spectral image slicers or narrowband filters.

The future: mapping the origins of the CGM gas





Lehner+ (2015)



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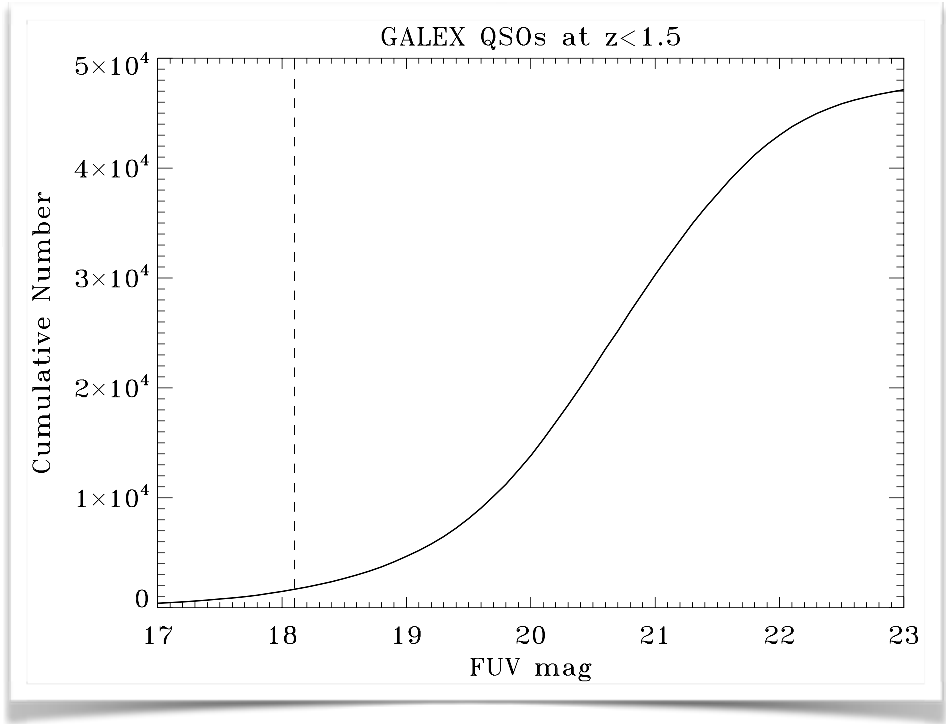
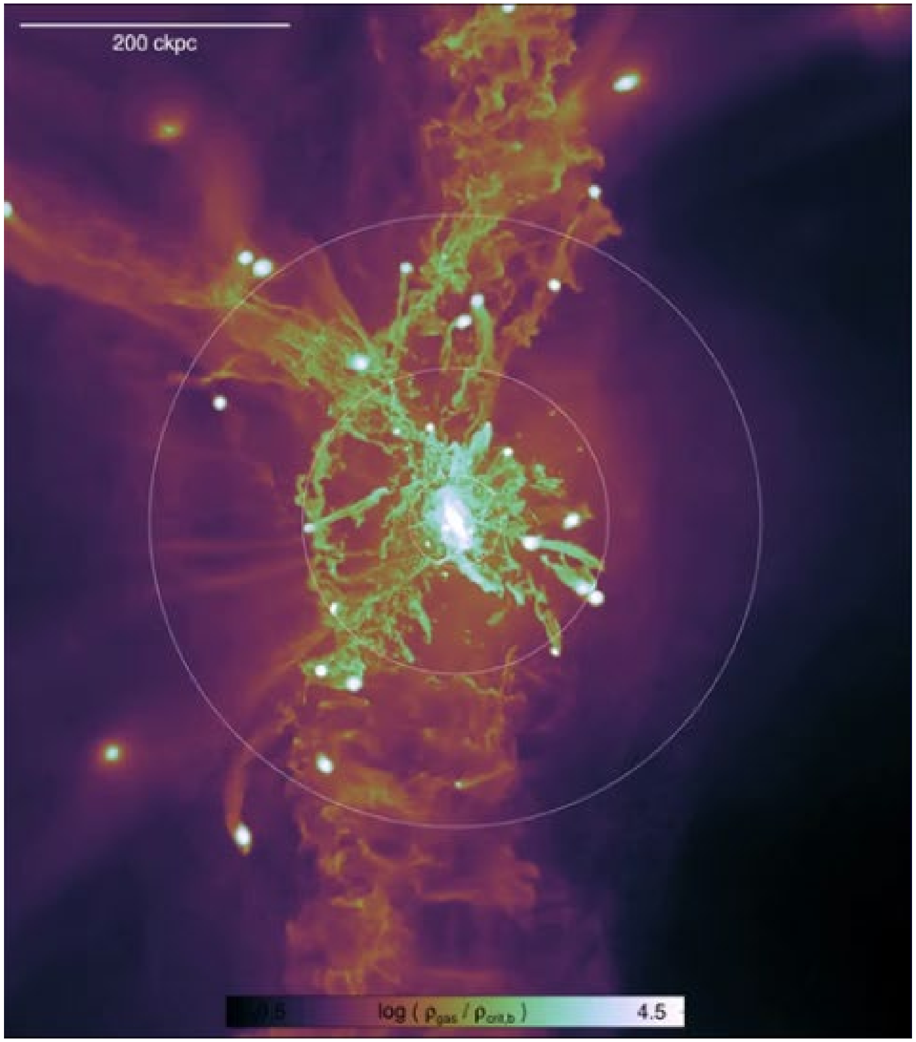


The future: connecting galaxies to the cosmic web



Nelson+ (2015)

2) We want to **connect** the CGM directly to structures in the cosmic web, trace CGM with environment.

We'd like to understand the filament/ CGM interaction at ~R_{vir}.

This means:

– Extending mapping of CGM to large scales.

– Tracing structures via spatial / metallicity information.

– Tracing the hot coronal matter to ~R_{vir}.

Critical capabilities:

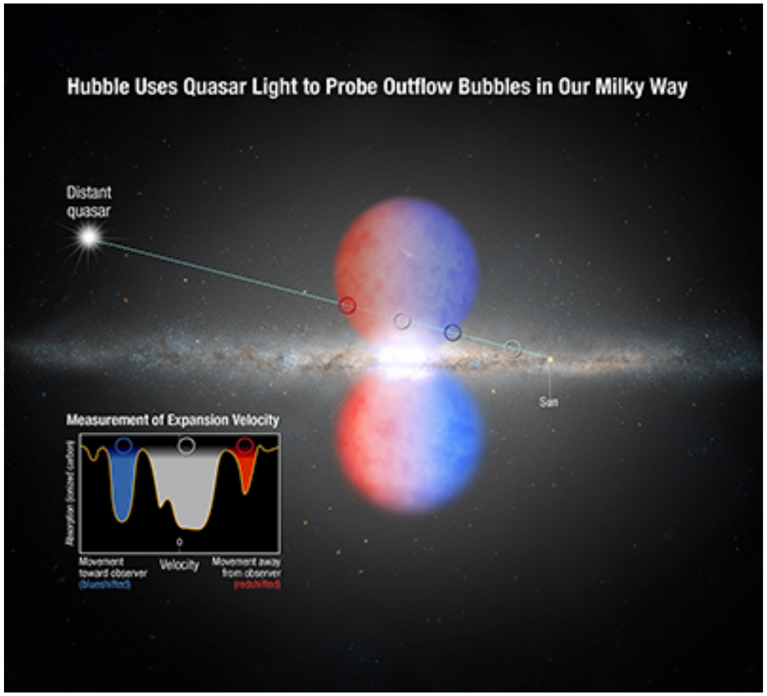
– ***Large aperture (sensitivity).***

– High resolution (R>20,000)? Could use moderate resolution (R~5000+) for H I.

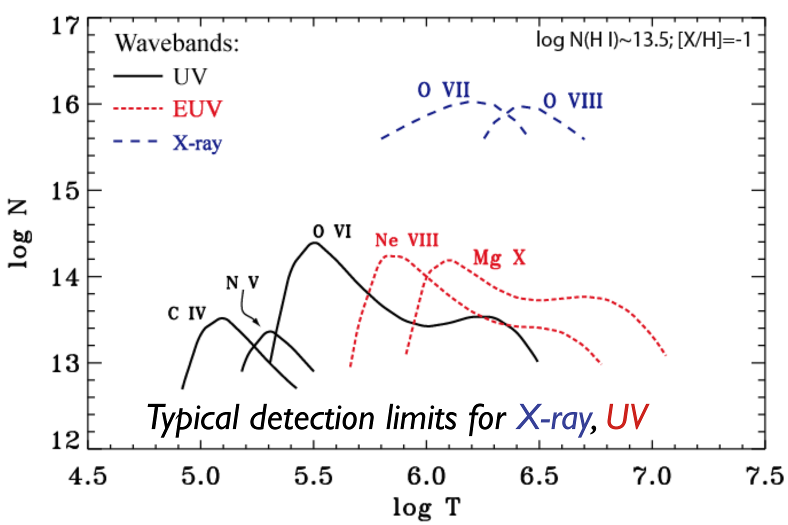
– FUV sensitivity to ~1000 Å, though NUV sensitivity better for H I.

– Multi-object spectroscopy on large angular scales?

The future: probing galactic outflows on large scales



We are only probing the swept up gas with low ionization studies. We need to cover high ions in order to measure the driving fluid + metals.



3) We want to map galactic winds on scales from ~few kpc to R_{vir} to capture the **redistribution of mass, metals** in the CGM and their return.

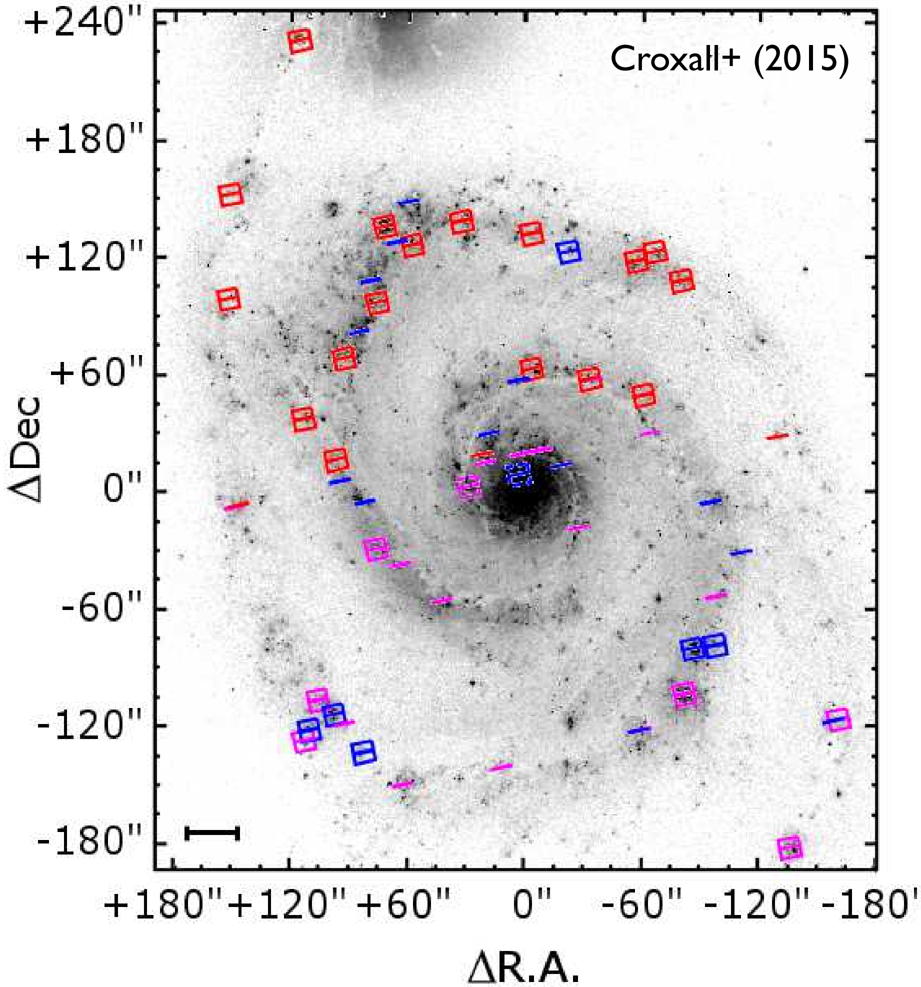
This means:

- Using *down-the-barrel* experiments to trace outflows at their source(s).
- Mapping more extended regions with background QSOs.
- Capturing the broadest possible range of ions, esp. those tracing the hot gas (e.g., O VI, Ne VIII @ z~0.3).
- ***Emission line imaging (in resonance lines)?***

Critical capabilities:

- Large aperture (sensitivity).
- **FUV capability to ~1000 Å.**
- High resolution (R>20,000) + moderate resolution (R ~ 5000+).
- …or UV imaging sensitivity, perhaps spectral image slicers or narrowband filters.

The future: probing origins of galactic outflows



Imagine these as individual UV slits for which we obtain R~5000+ spectra.

Such a capability could be especially powerful on larger scales against redshifted galaxies for mapping H I absorption.

4) We want to map the origins of outflows across galaxies, understanding the dynamics of both **fountains** and **winds**.

This means:

– Using *down-the-barrel* experiments to trace outflows at their source against individual star forming regions.

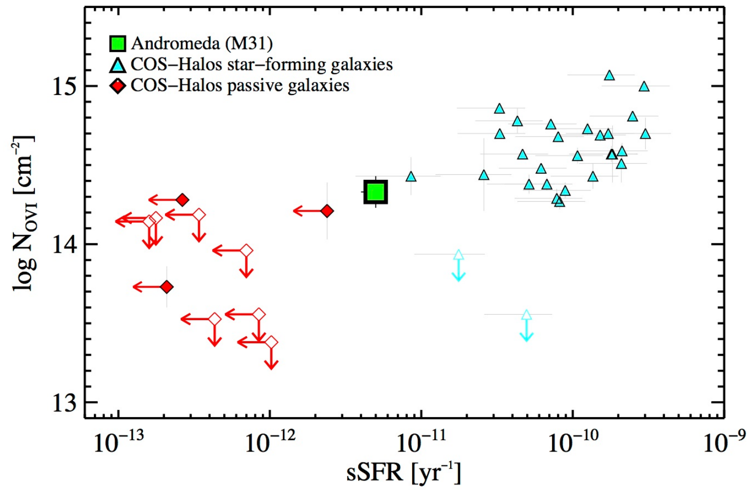
– Leveraging multi-object capabilities.

Critical capabilities:

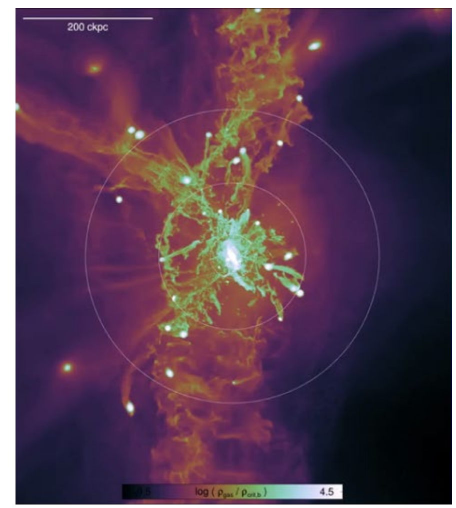
– Multi-object capability.

– Moderate resolution (R ~ 5000+).

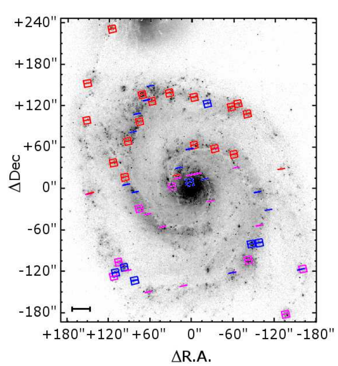
Food for thought: the CGM with HDST



- CGM studies with COS have clearly demonstrated the CGM of galaxies is intimately connected to how they evolve.
  - *Working at low-redshift in the UV has huge advantages in terms of making connections to galaxies, lack of confusion for FUV/EUV lines.*



- A future large aperture mission – even if only equipped with an HST-like complement of spectrographs – would enable us to understand *how* the CGM drives galaxy evolution.
  - *The important questions of the mode of accretion, connection to the cosmic web, driving of winds, total metal content, ionization mechanisms can be addressed.*



- Novel approaches with MOS could allow mass-production surveys of bulk CGM properties, especially in parallel with other programs.
  - *In fact, we probably NEED to have advances in multiplexing, technologies to justify the extreme cost.*