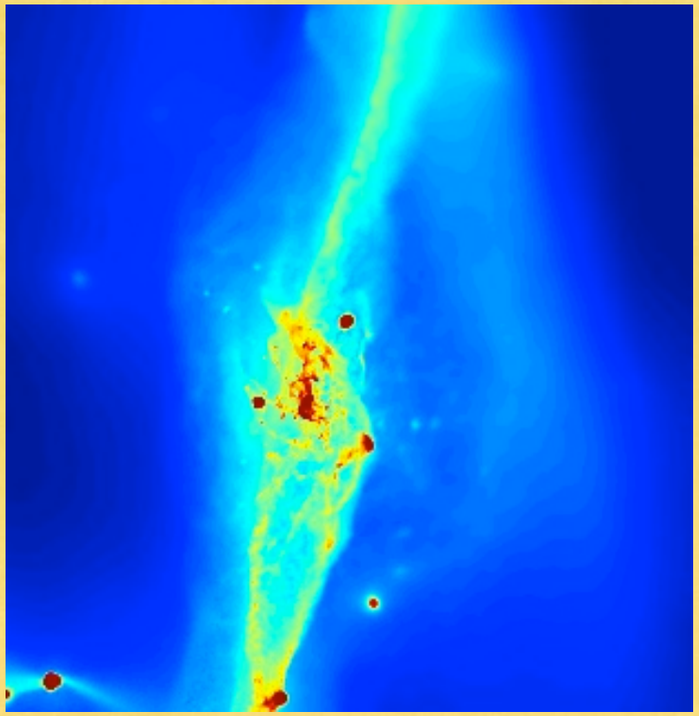
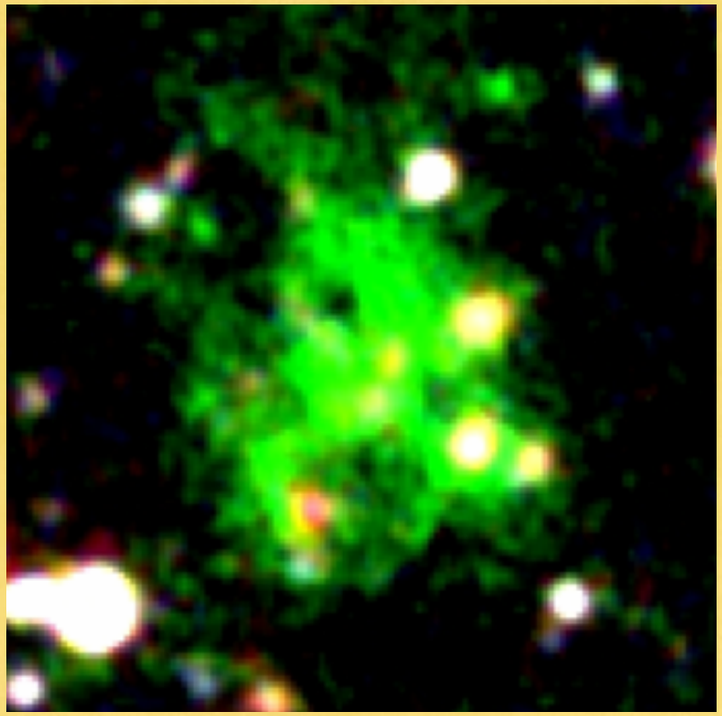
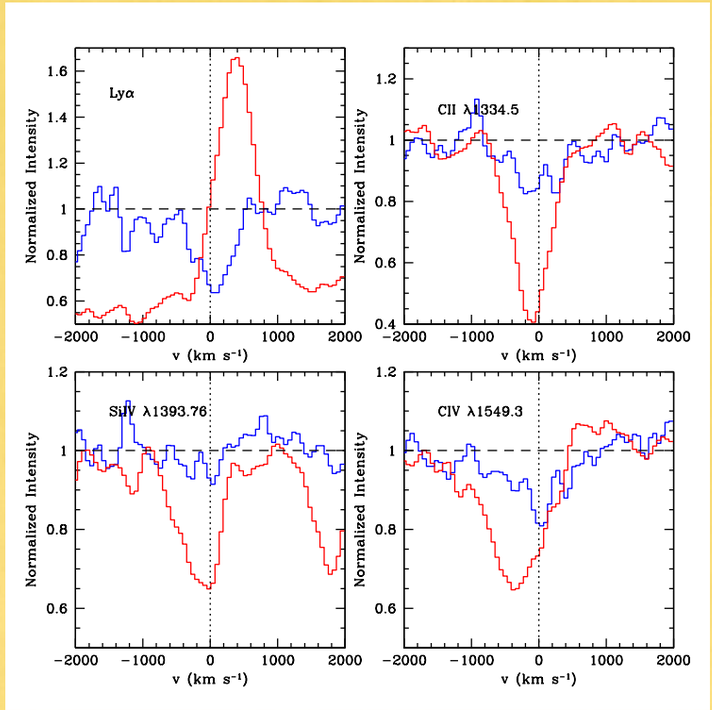
Modeling the Signatures of Galactic Gas Accretion







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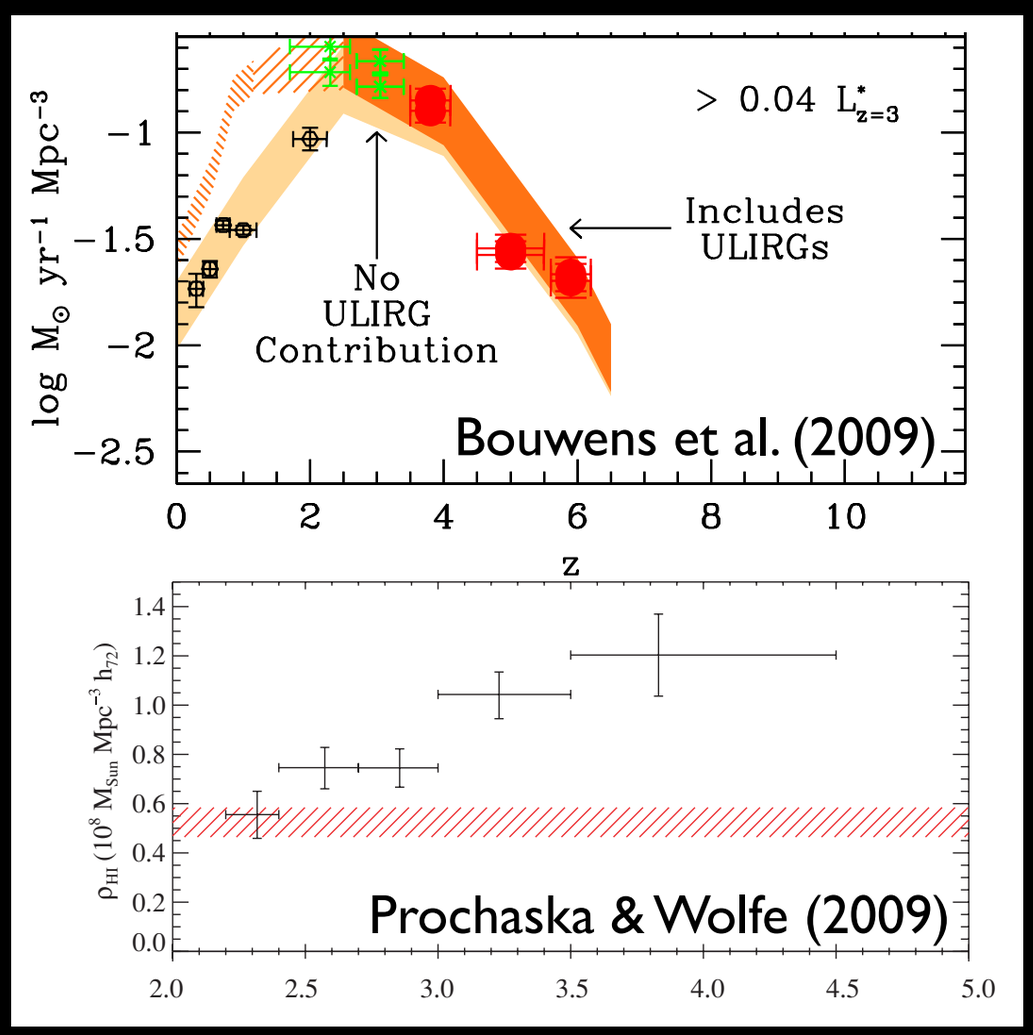
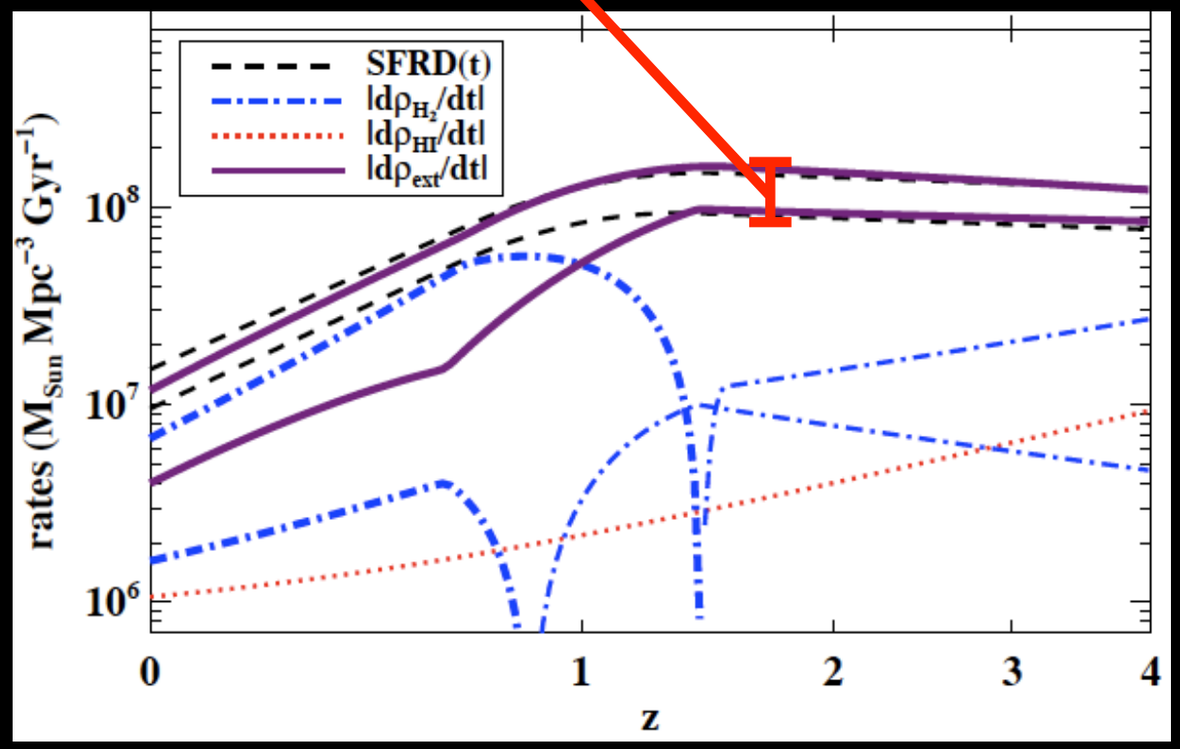
The Need for Sustained Accretion

- Galaxies deplete their H_2 on time scale ~Gyr $\ll t_H$
- Measured HI reservoir vs. z is insufficient
- Must be continuously replenished by accretion of ionized gas from the IGM!



need IGM accretion ~ SFR

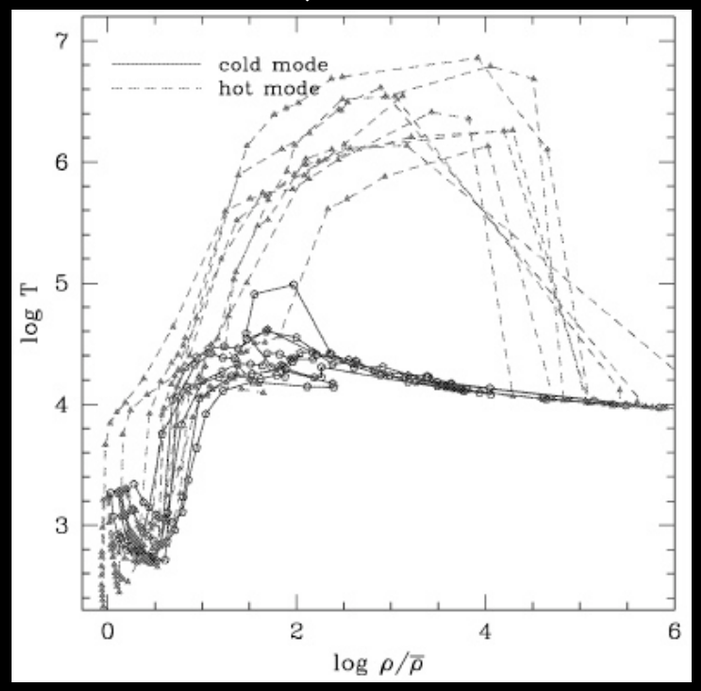


Bauermeister, Blitz, & Ma (2009)

Cold vs. Hot Modes

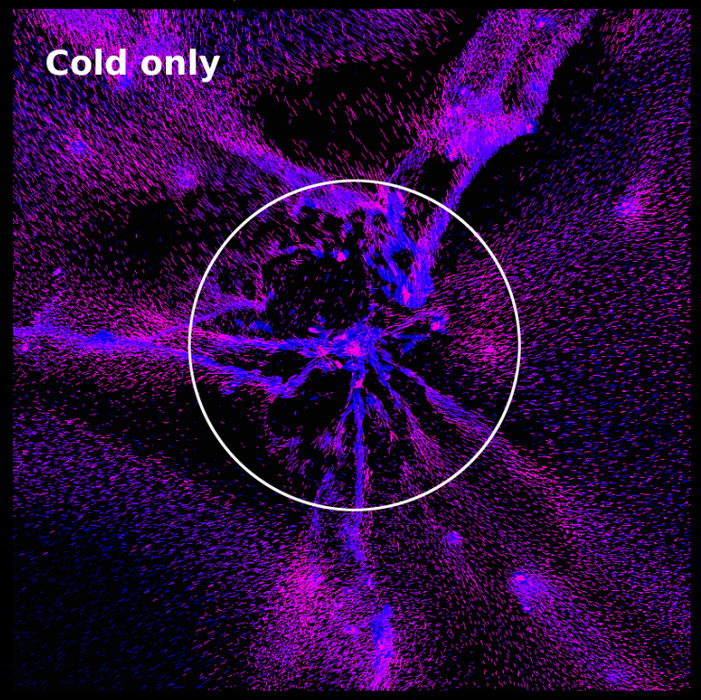
- Gas accretion is *predicted* to be bimodal:
  - ➡ cold mode: most accreted gas is never shock heated to T_{vir} and maintains $T<2.5\times10^5$ K
  - ➡ hot mode: smaller fraction shock heats and cools as in classical picture
- Confirmed in SPH, AMR, and Lagrangian mesh numerical simulations

T trajectories



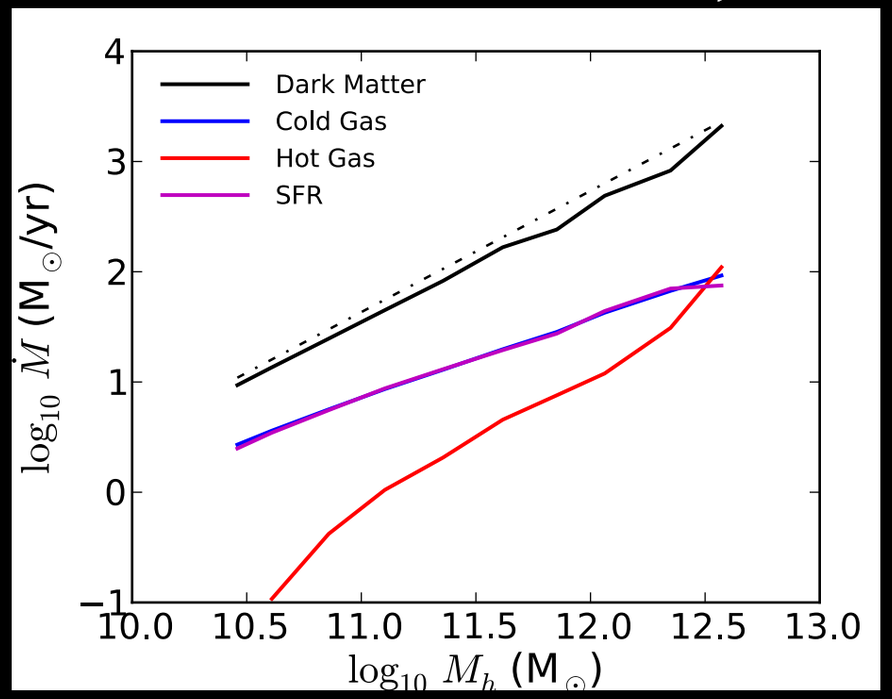
Kereš et al. (2005)

z=2, M_h~10^{12} $M_\odot$



Kereš et al. (2009)

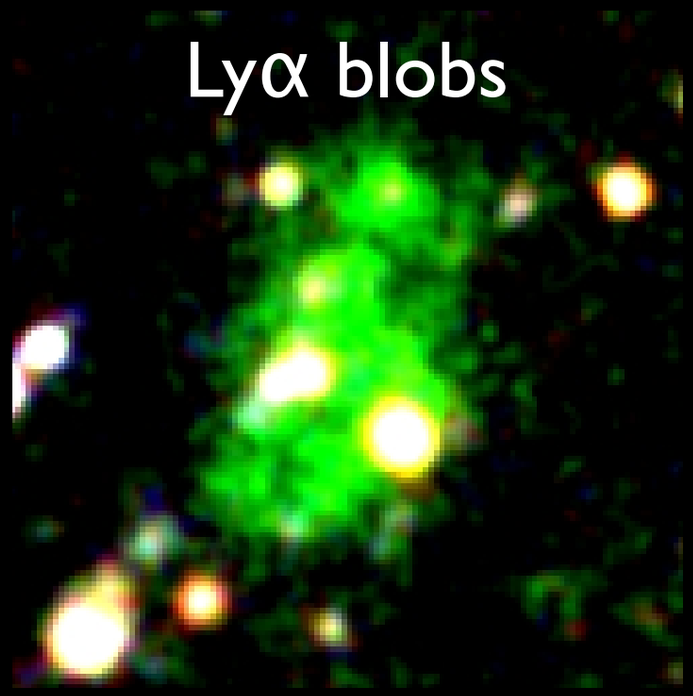
Halo accretion rates vs. *M_h, z=3*

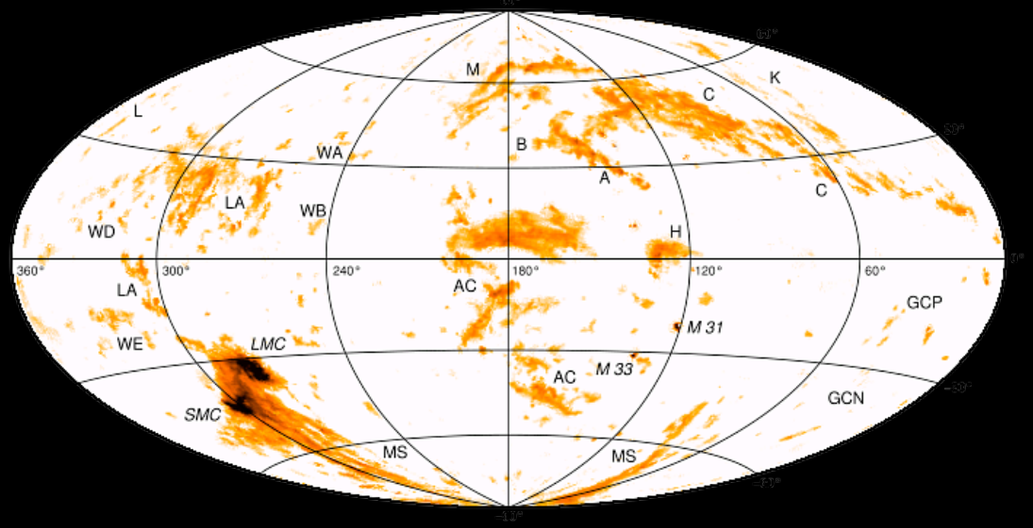


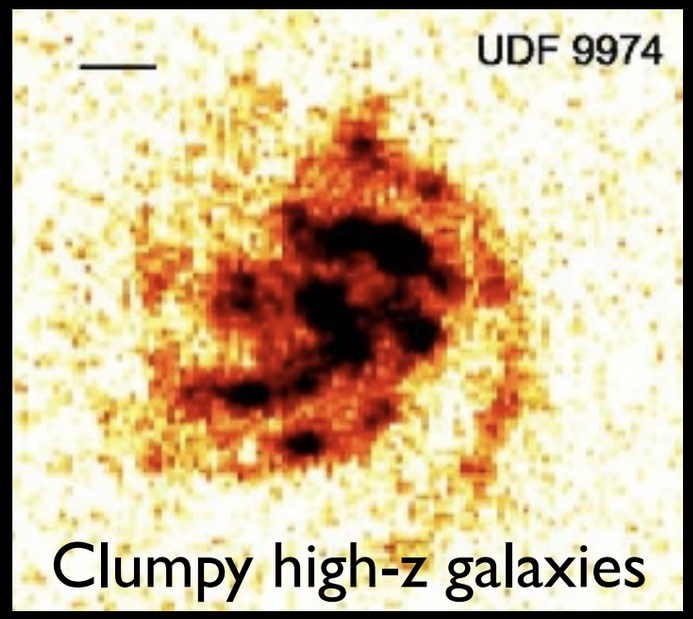
CAFG, Kereš, Ma, in prep.

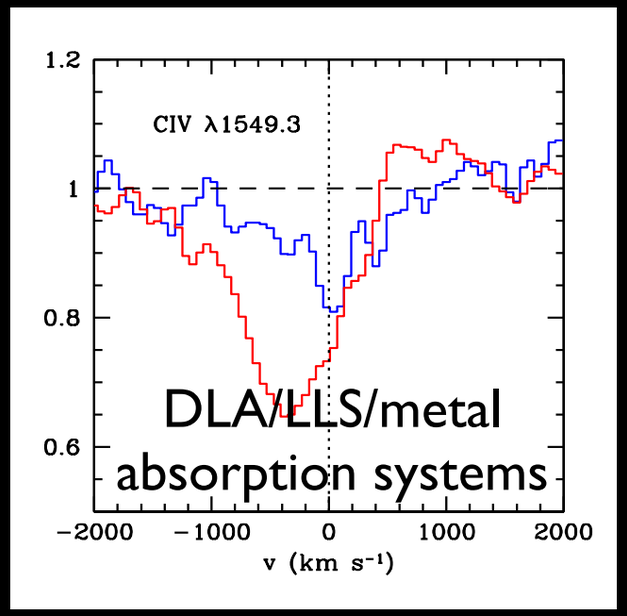
Connections to Observed Phenomena?

- *Could* be connected to a host of observed phenomena:





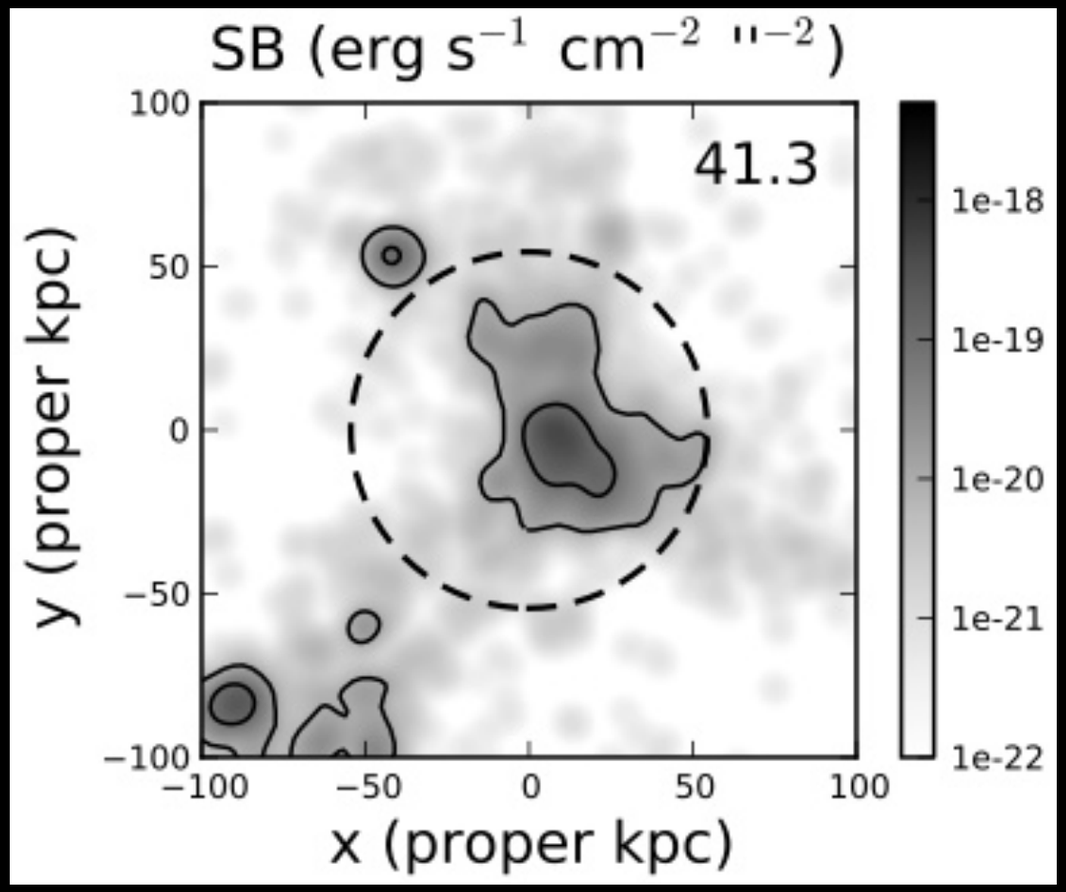




- *But*, are they?

Lyα Emission & Absorption

- As part of this research program, we have so far studied the Lyα emission and absorption properties of the cold streams at z~2-4
- Using hydro simulations with ionizing + Lyα line RT, we showed that pure cooling cannot explain the observed giant Lyα blobs, with $L_\alpha \sim 10^{44}$ erg s^{-1}:
  - ➡ Lyα luminosity too small
  - ➡ line spectrum inconsistent with observed outflow signatures
- Most likely, they are manifestations of feedback processes
- Some fainter sources (e.g., Rauch et al. 2008) could be powered by cooling
- Today, I will focus on absorption



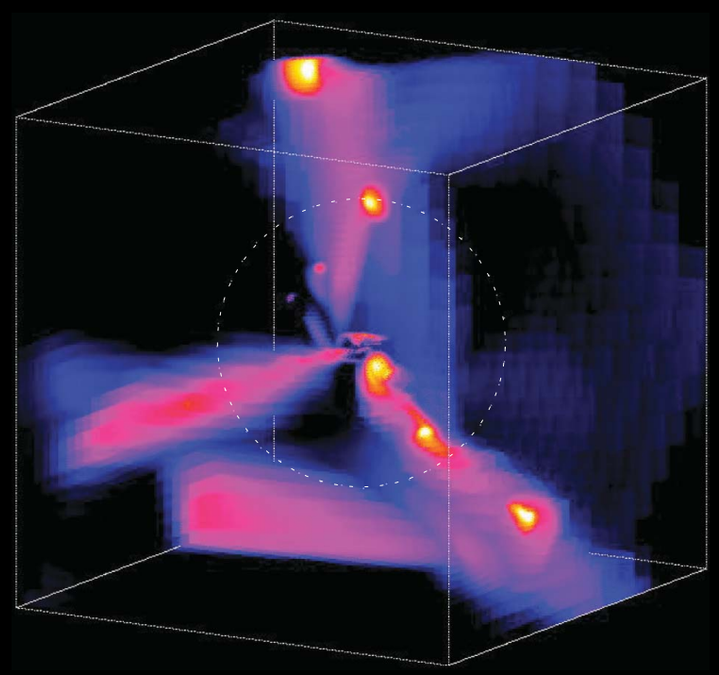
CAFG et al. (2010)

Observational Puzzle

- So far, little trace of *infalling* cool material around z~2-3 galaxies:

Dekel et al. (2009) - theory

"When viewed from a given direction, the column density of cold gas below 10^5 K is above 10^{20} cm^{-2} for 25% of the area within the virial radius."



Steidel et al. (2010) - obs.

"In any case, there seems to be no way to reconcile the observed CGM absorption line strength and kinematics with the results of simulations"

<u>Based on:</u>

- 1000s of LBGs
- including 512 close pairs

see ubiquitous outflows, but little infall

- A problem for the cold mode?

Theoretical Issues

- Focus on the *covering factor of high-z cold streams*

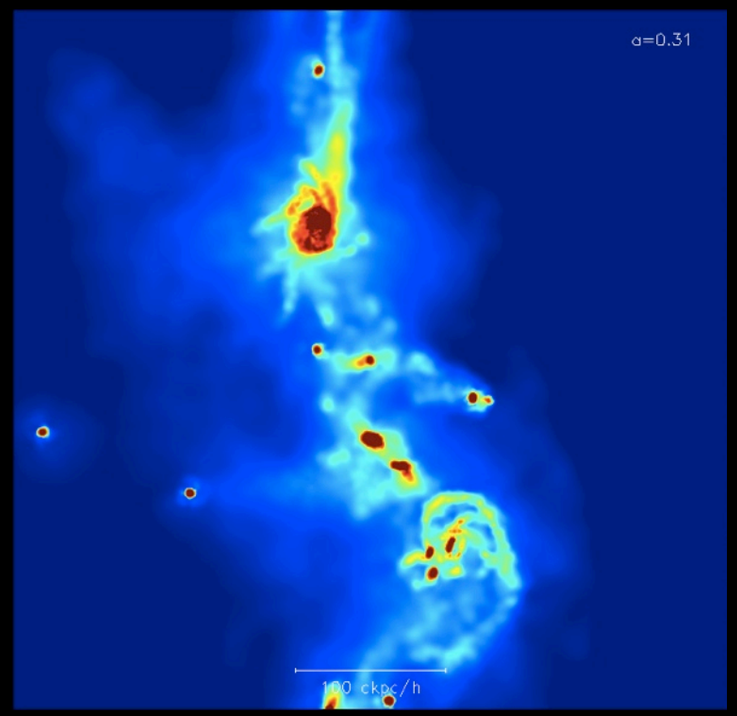
- Basic numerical requirements:

  ➡ need high-resolution to model the thin filaments

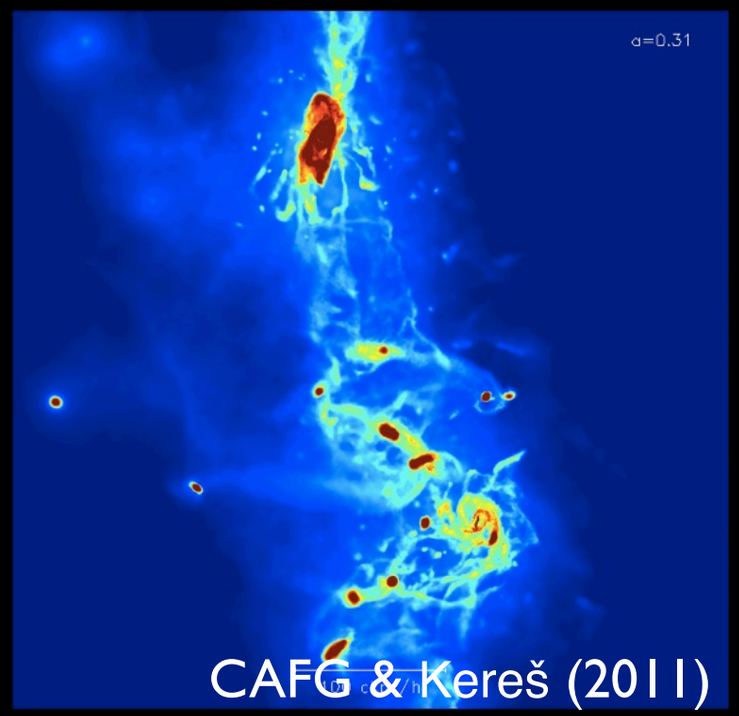
  ➡ need RT to predict what we measure, HI

- As for Lyα emission, look at simplified problem of pure accretion in ΛCDM

10^6 $M_\odot$ res.



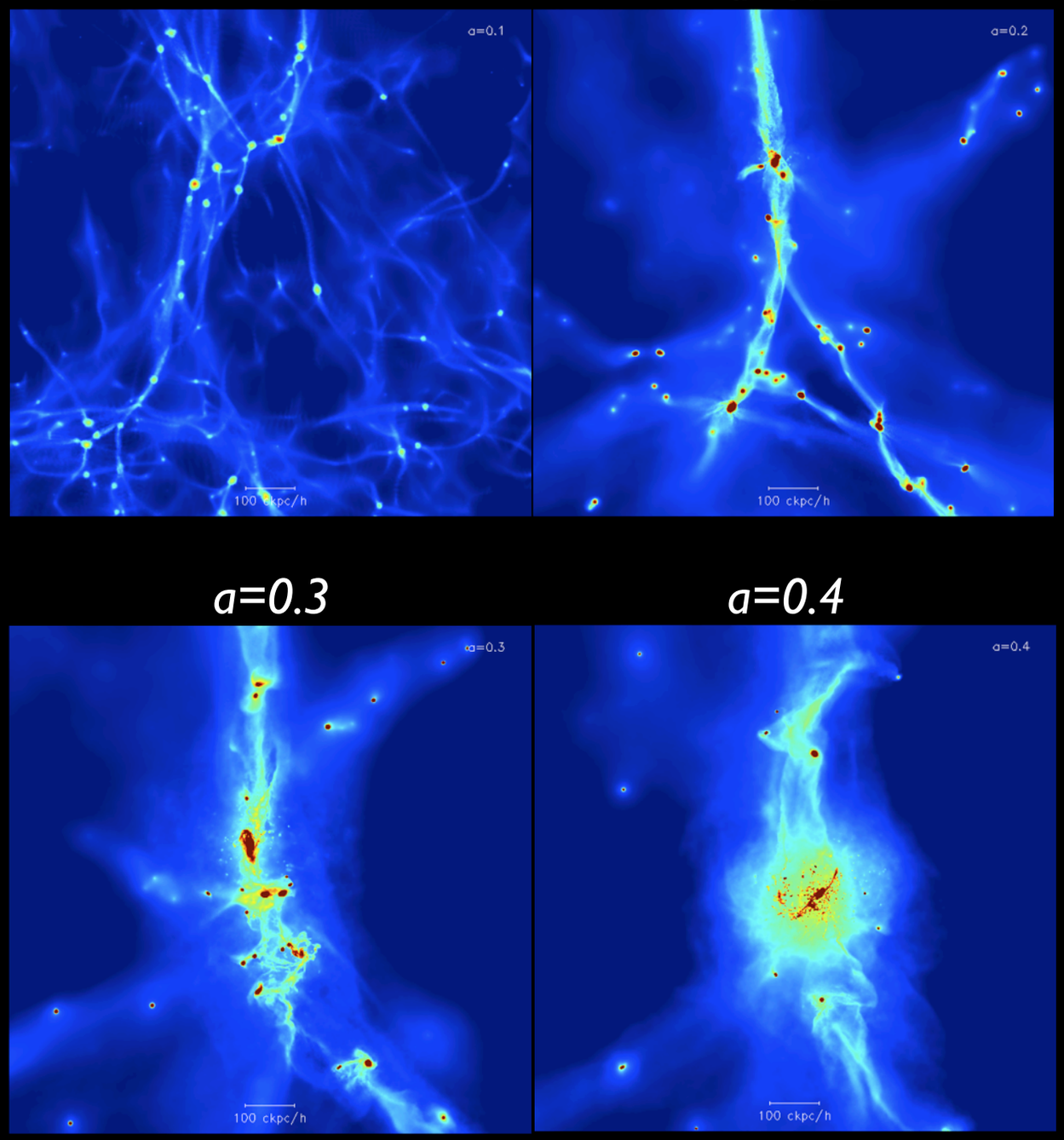
27x better



CAFG & Kereš (2011)

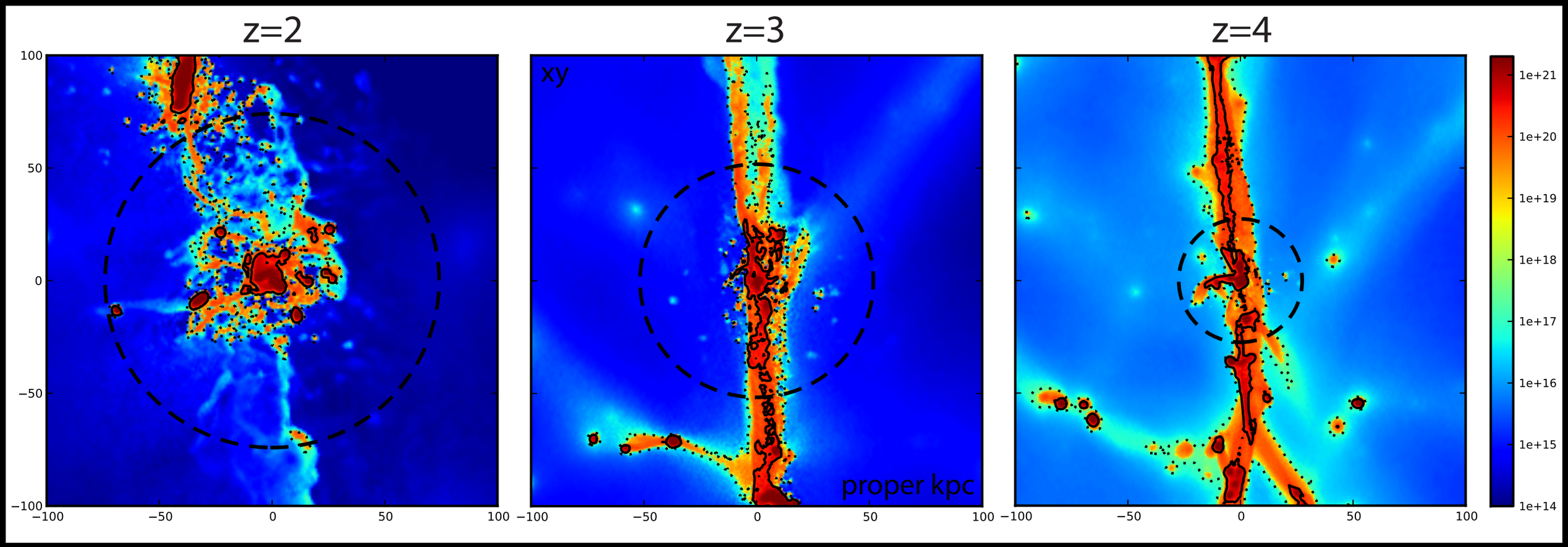
Numerical Setup

- Zoom-in simulations for very high resolution
  - ➡ 27 proper pc gas smoothing length achieved at z=2
  - ➡ ε=275 comoving pc/h Plummer equivalent gravity
- MW progenitor, LBG at z~2-3
- Ionizing RT
  - ➡ UV background (CAFG 2008a,b, 2009)
  - ➡ local sources
- Lower-resolution runs to check convergence, variance



CAFG & Kereš (2011)

HI Stream Covering Factor



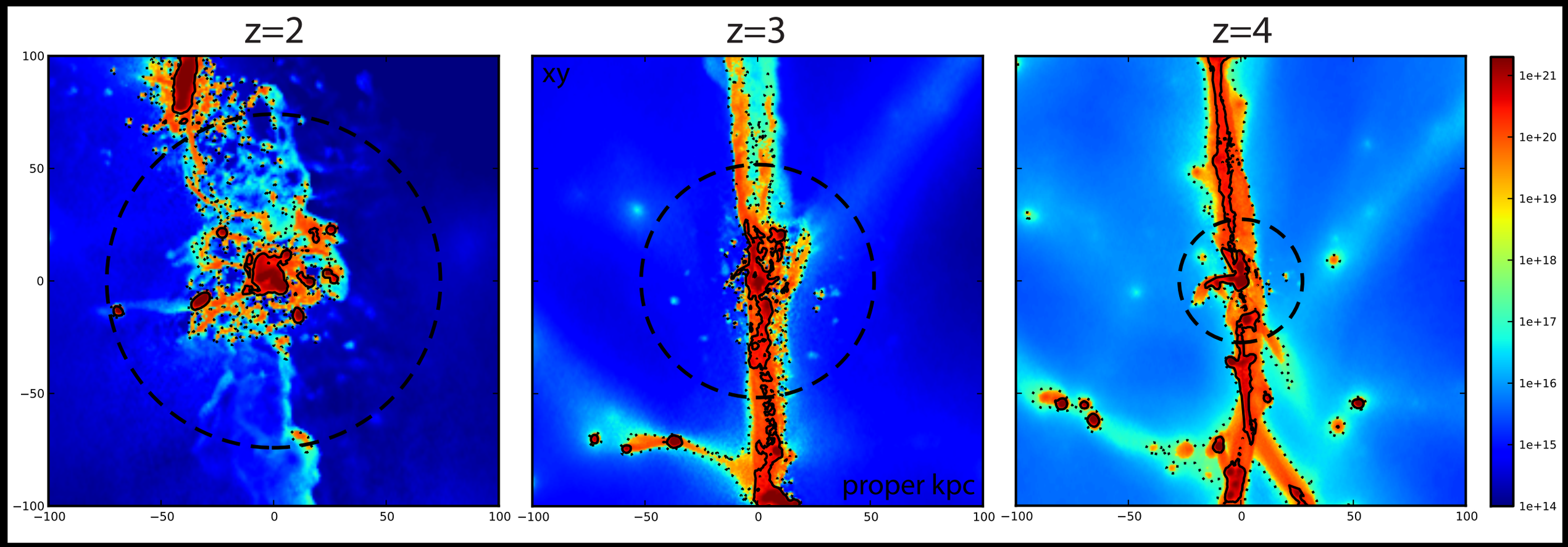
CAFG & Kereš (2011)

Within 1 R_{vir}

LLS:	10%	16%	30%
DLA:	3%	6%	11%

The DLA covering factor of accretion streams at z~2, where observations are most sensitive, is only a couple %, and mostly from the galaxy.

HI Stream Covering Factor



CAFG & Kereš (2011)

Within 1 R_{vir}

	z=2	z=3	z=4
LLS:	10%	16%	30%
DLA:	3%	6%	11%

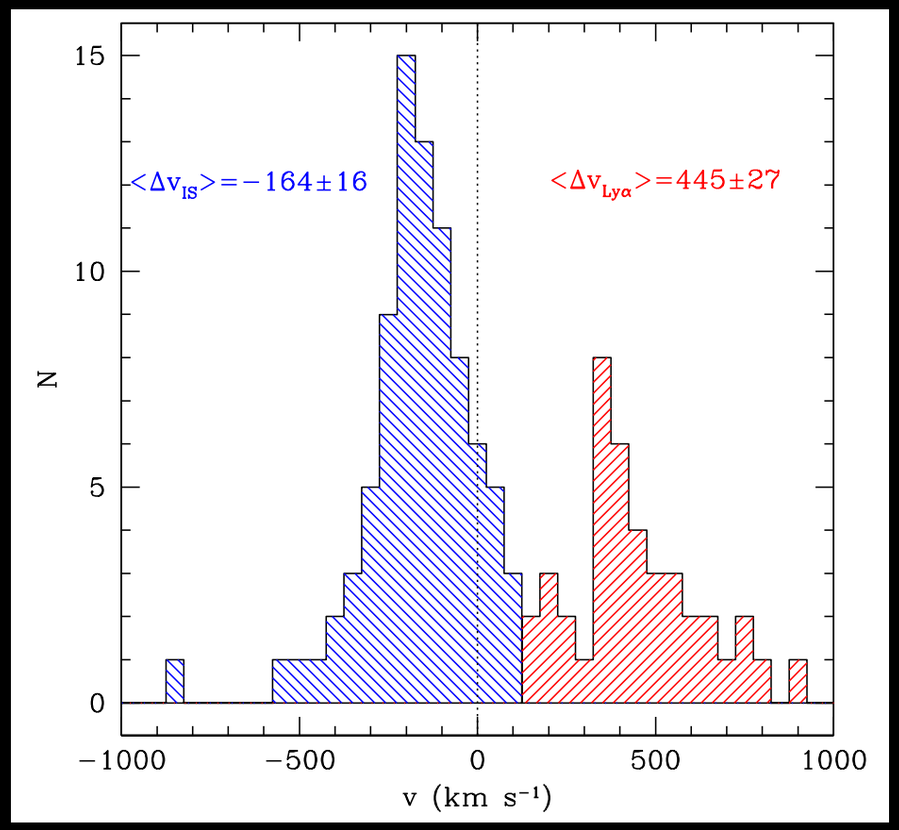
The DLA covering factor of accretion streams at z~2, where observations are most sensitive, is only a couple %, and mostly from the galaxy.

Compare with Winds

- Galactic outflows were not included in the current simulations, but we know they are there in reality:

In LBGs, interstellar absorption (almost) always blueshifted, Lyα emission always redshifted

⇒ winds with ~1 covering factor

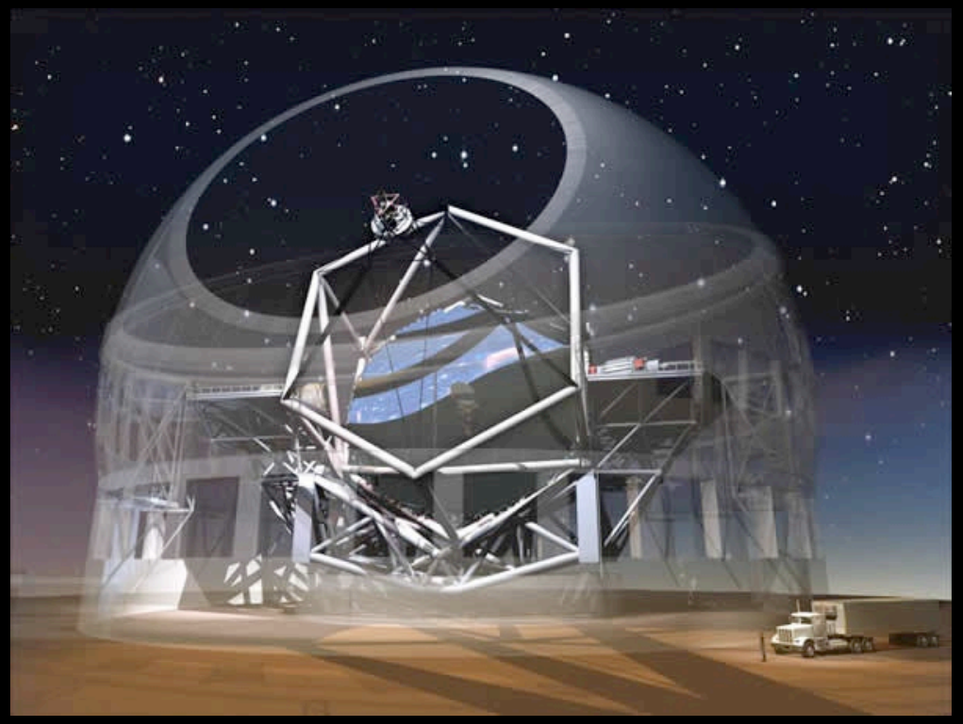


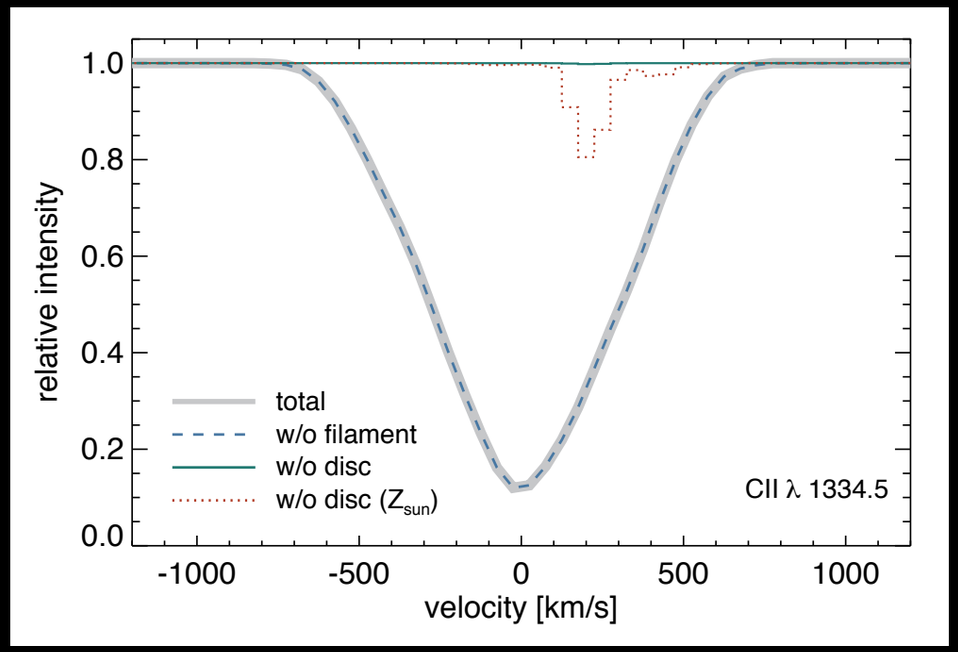
Steidel et al. (2010)

- At z~2, where cold streams covering factor << 1, stacked spectra are naturally dominated by winds
- The cold mode predictions are therefore consistent with current non-detections

How to Detect the Cold Streams?

- More galaxy pairs, ideally quasar-galaxy or galaxy-galaxy with 30 m class telescope to get individual spectral measurements
  - ➡ Kinematics (accretion at $v \sim v_{circ}$ vs. outflows up to ~800 km/s)
  - ➡ Metallicity ($Z_{infall} < Z_{wind}$)
  - ➡ Need statistics since $f_{cov} \ll 1$
  - ➡ Ideal targets for future IFUs
- Better theoretical modeling
  - ➡ outflows
  - ➡ metals





Kimm et al. (2010)

In single sight lines, infalling material with $v \sim v_{circ}$ tends to be masked by ISM absorption

Summary

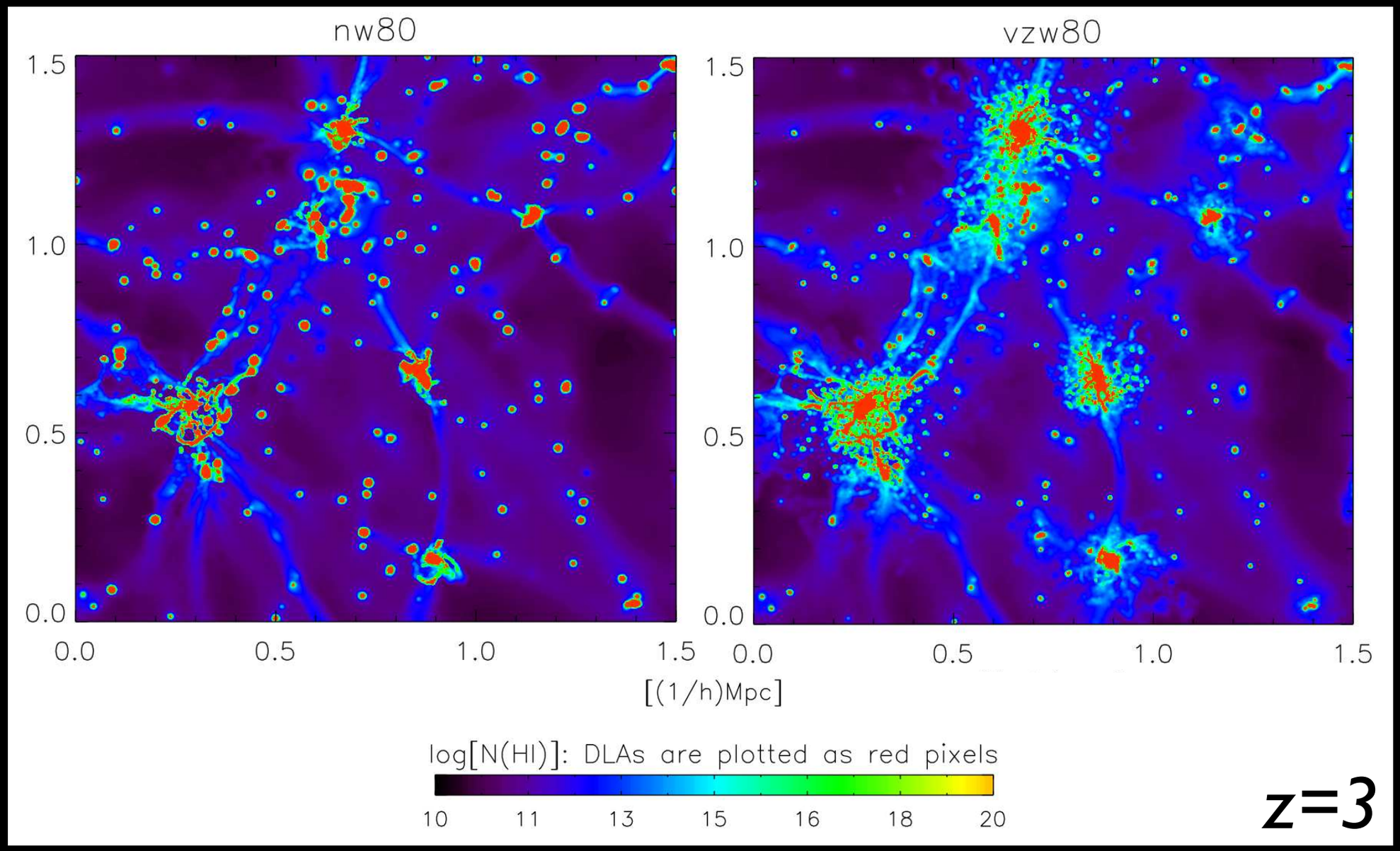
- Our studies of Lyα cooling emission and absorption show that it is quite subtle to detect cold accretion
- Getting at it will require robust theoretical studies in concert with detailed spectroscopic measurements of the circum-galactic medium of high-redshift galaxies
- The most promising diagnostics of infall vs. outflows are:
  - ➡ kinematics (accretion at $v \sim v_{circ}$ vs. outflows up to ~800 km/s)
  - ➡ metallicity (expect $Z_{infall} < Z_{wind}$, but by how much?)
- Need enough measurements because of small covering factor
- Future modeling will include outflows and metals

Extra Slides

Impact of Winds

- Momentum-driven galactic winds fill the virial radii of LBGs with Lyman limit systems:

No winds | Winds



Hong et al. (2010)