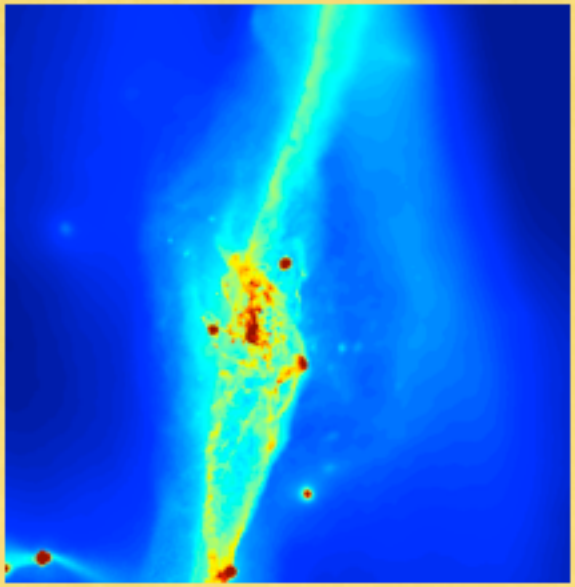
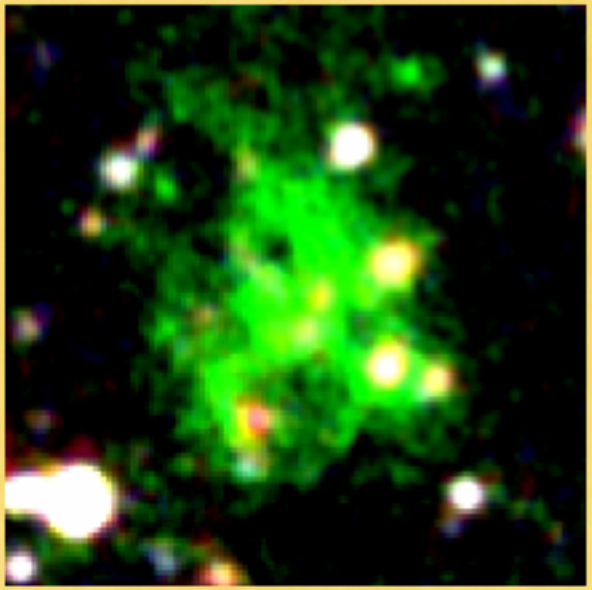
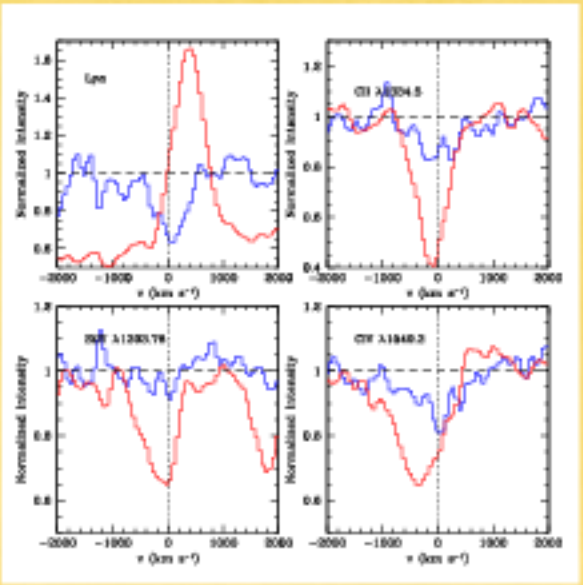
Modeling the Signatures of Galaxy Assembly







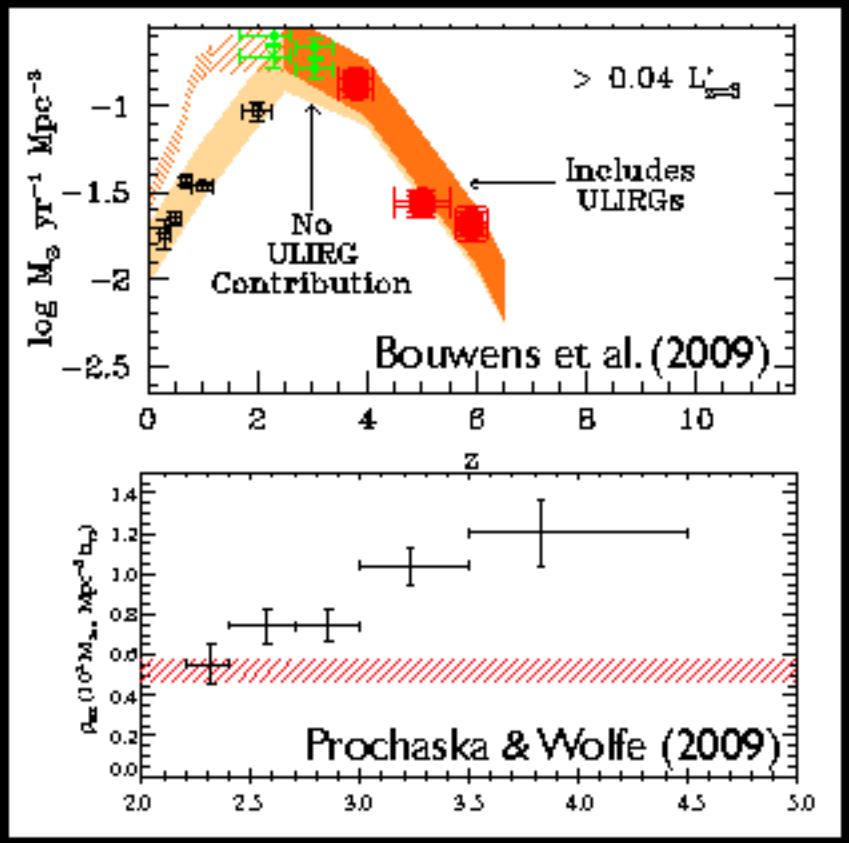
Claude-André Faucher-Giguère

UC Berkeley

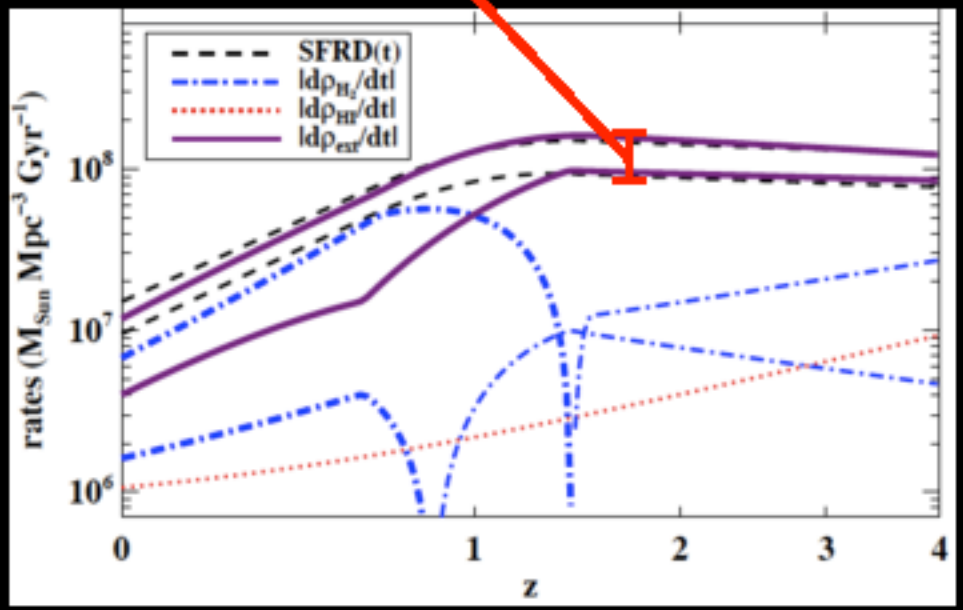
Miller Institute for Basic Research in Science

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

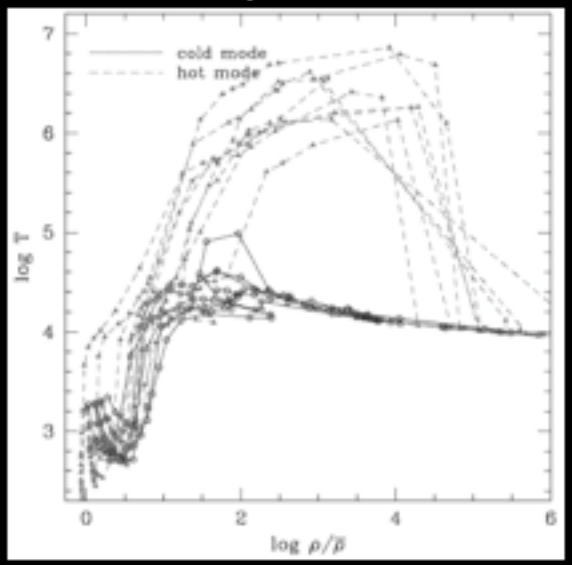


Bauermeister, Blitz, & Ma (2009)

Cold vs. Hot Modes

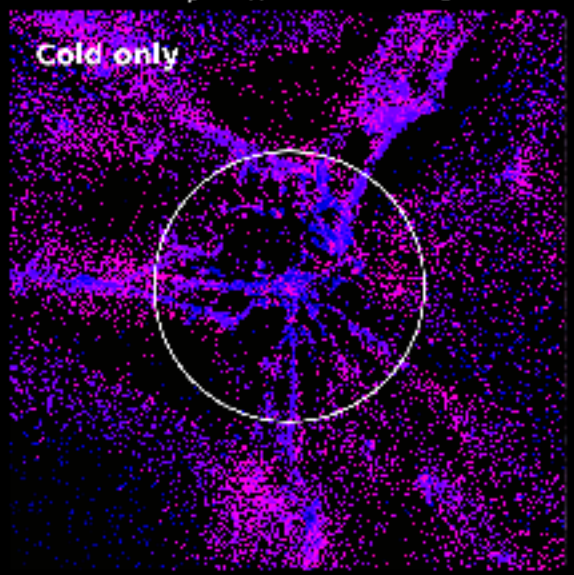
- Gas accretion is *predicted* to be bimodal:
  - ➡ cold mode: most accreted gas is never shock heated to T_{vir} and maintains $T<2.5\times10^5$ K
  - ➡ hot mode: smaller fraction shock heats and cools as in classical picture
- Found in both SPH and AMR numerical simulations

T trajectories



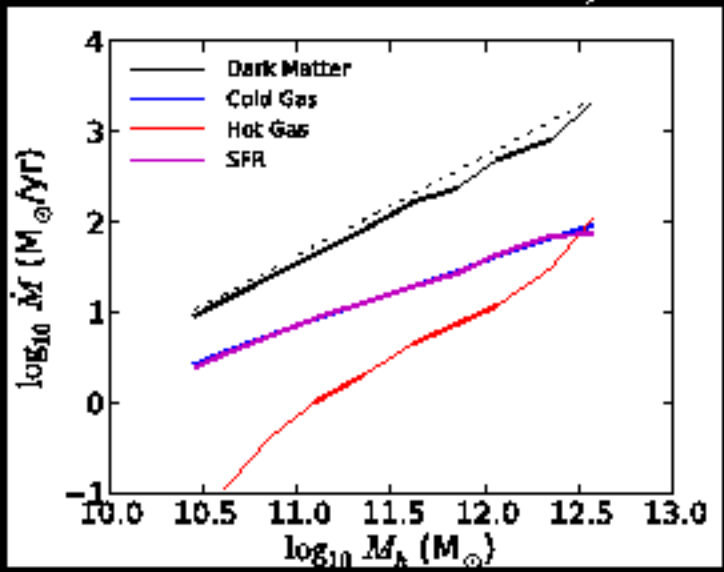
Kereš et al. (2005)

$z=2, M_h\sim10^{12}\ M_\odot$



Kereš et al. (2009)

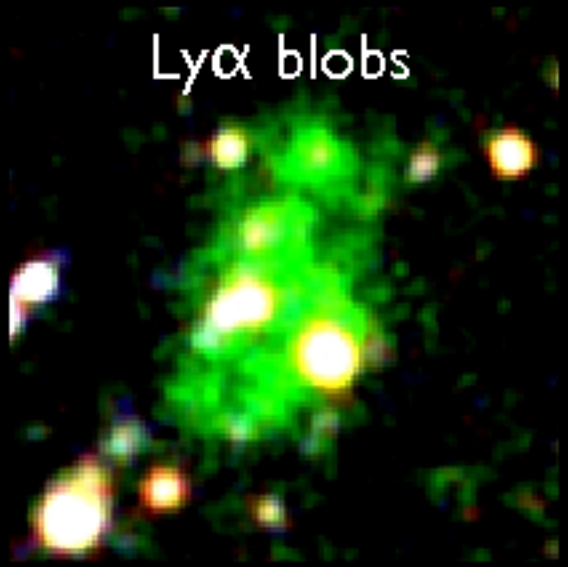
Halo accretion rates vs. M_h, $z=3$

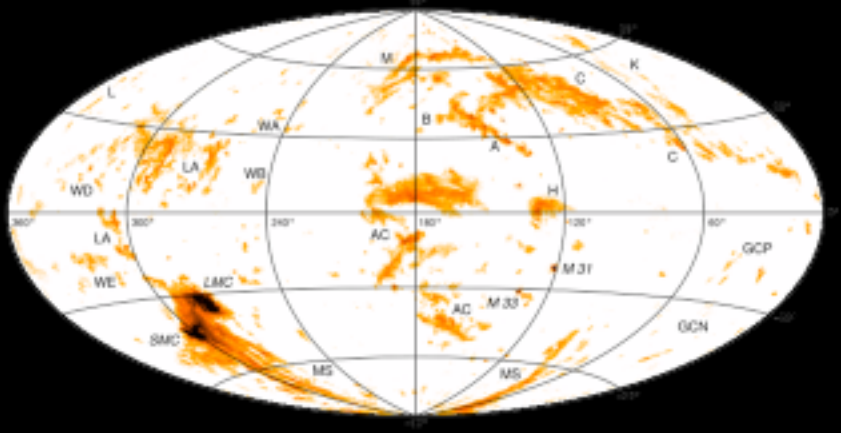


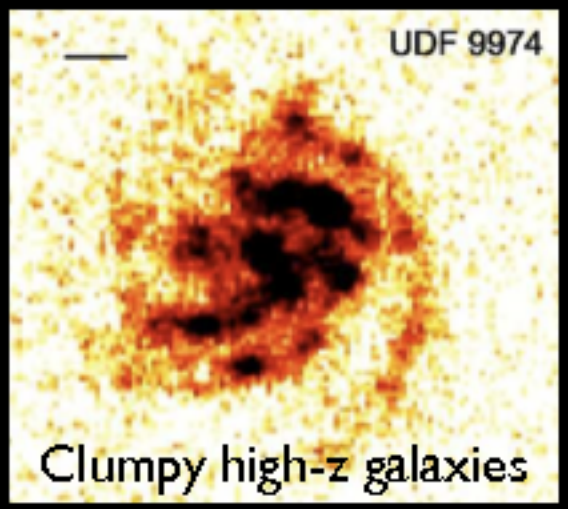
CAFG, Kereš, Ma, in prep.

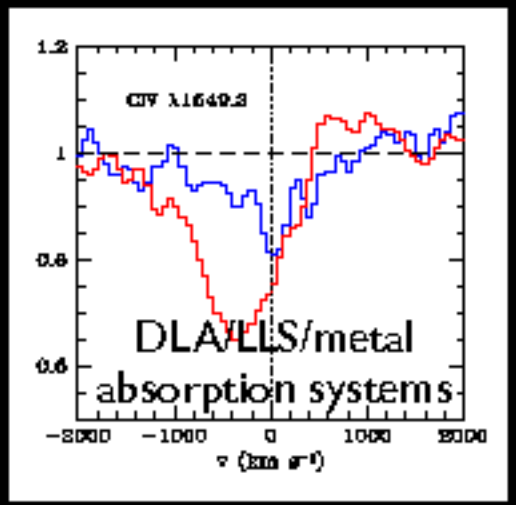
Connections to Observed Phenomena?

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









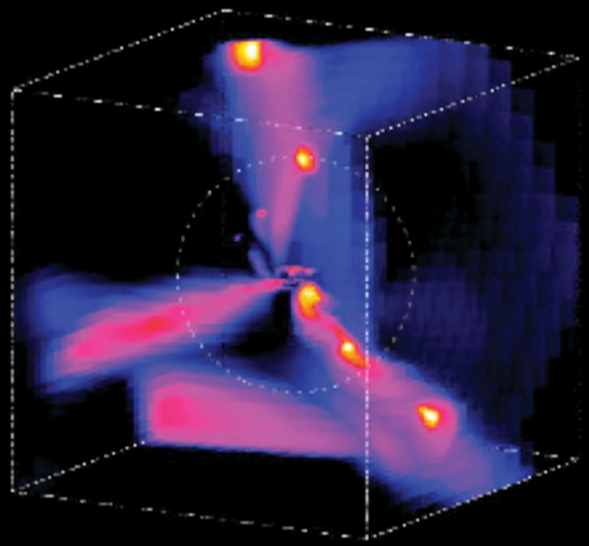
- *But*, are they?

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"

Based on:

- 1000s of LBGs
- including 512 close pairs

see ubiquitous outflows, but little infall

- A problem for the cold mode?

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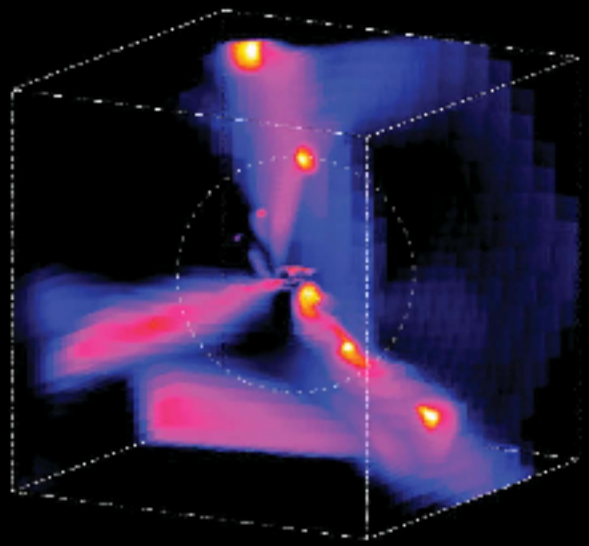

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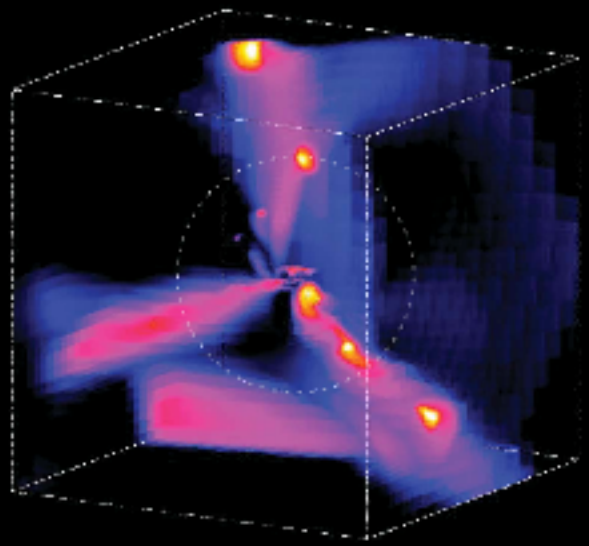

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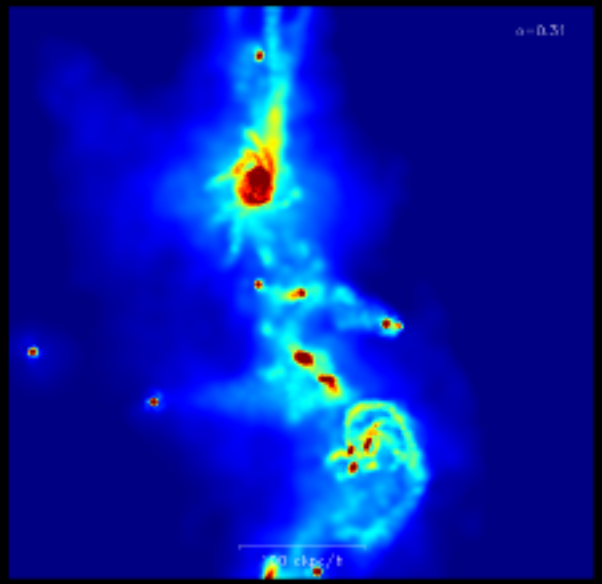
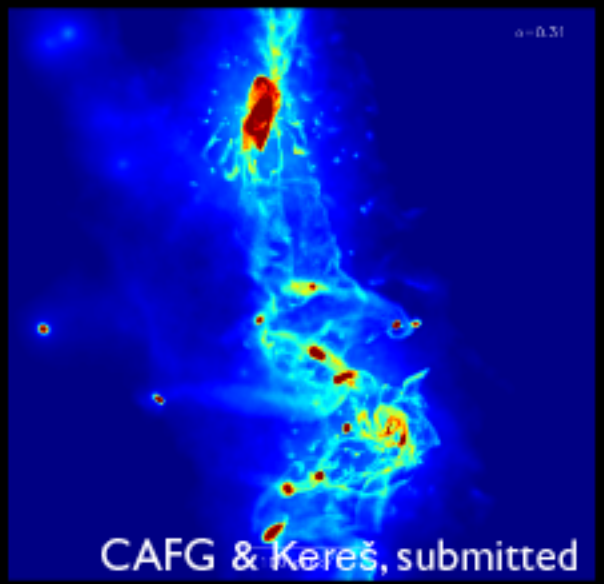
Theoretical Issues

- 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



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
- Milky Way progenitor, LBG at $z\sim2$-3
- Ionizing RT
  - ➡ UV background
  - ➡ local sources
- Lower-resolution runs to check convergence, variance

CAFG & Kereš, submitted

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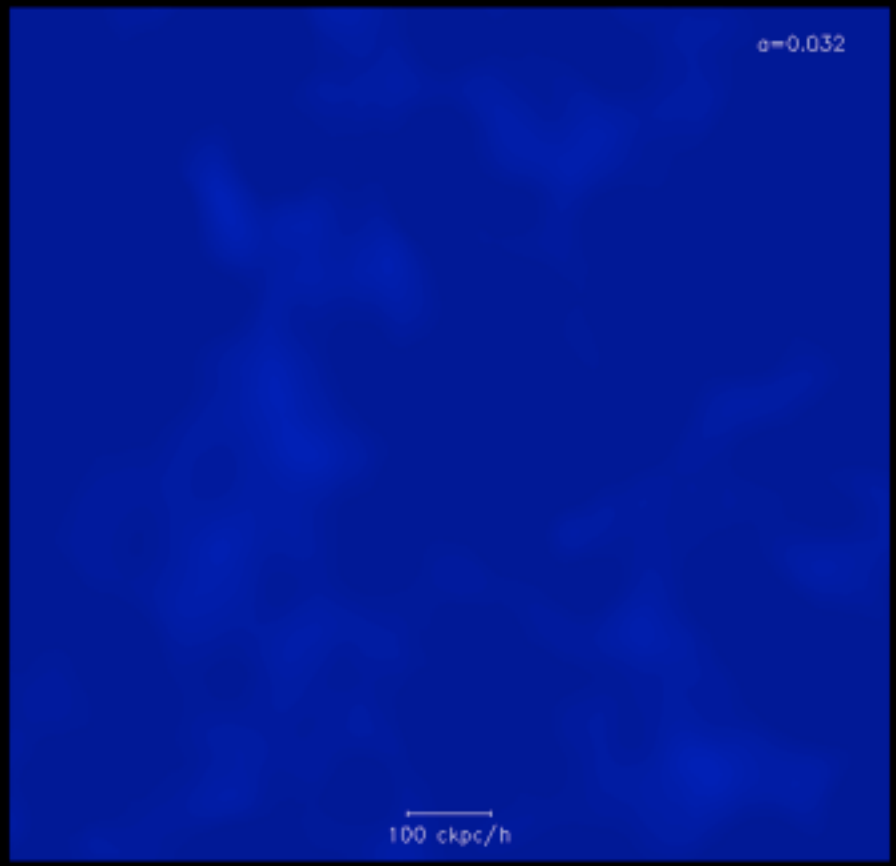
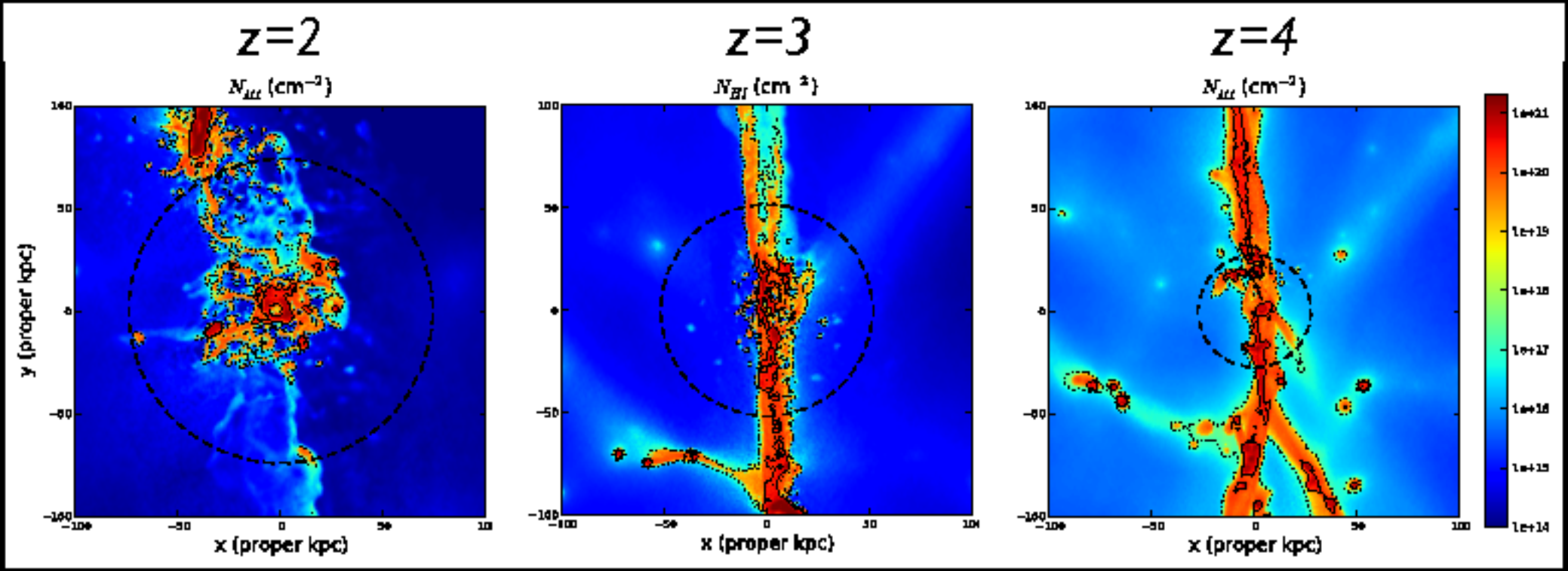


CAFG & Kereš, submitted

HI Stream Covering Factor



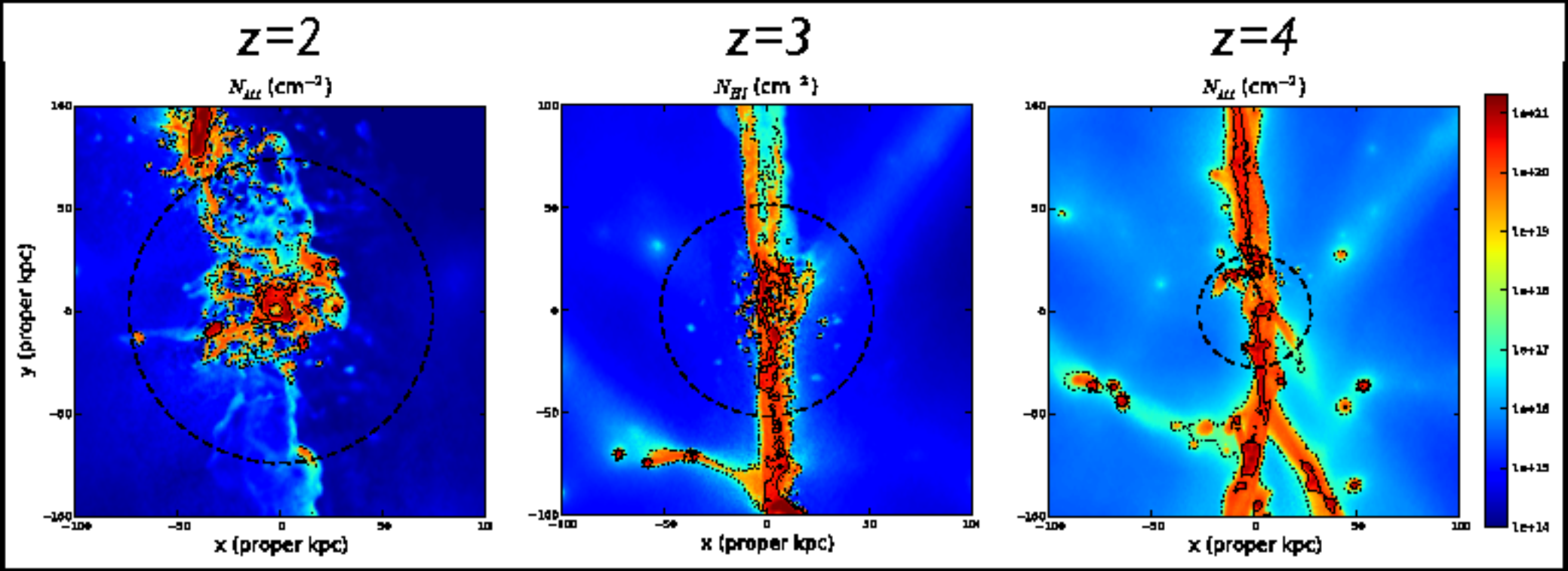
CAFG & Kereš, submitted

Within 1 R_{vir}

LLS:	11%	15%	30%
DLA:	2%	5%	9%

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



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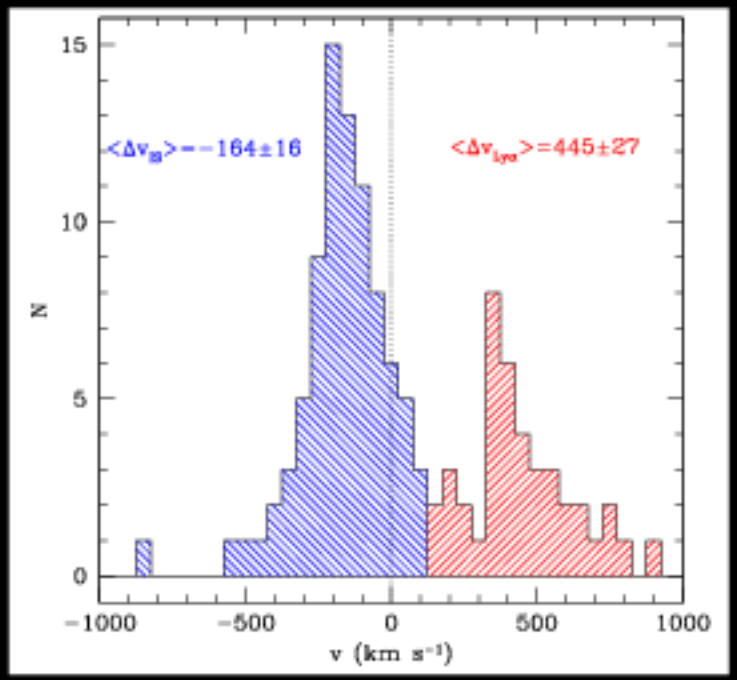
Compare with Winds

- 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

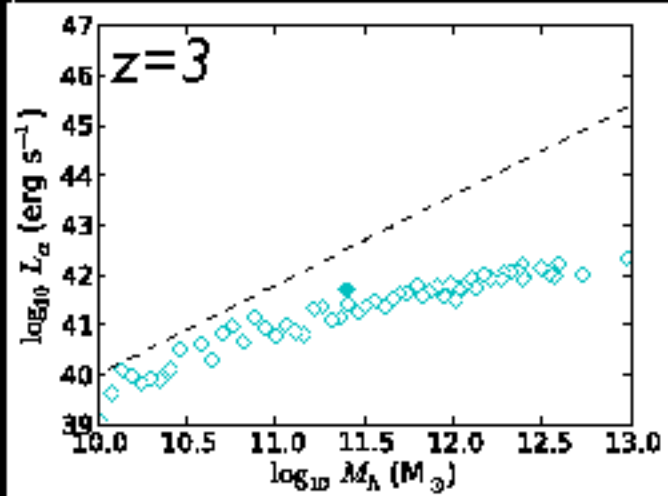


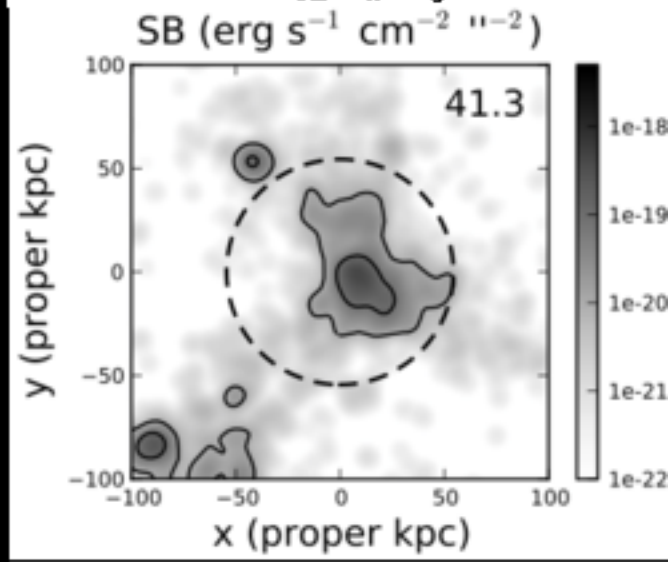
Steidel et al. (2010)

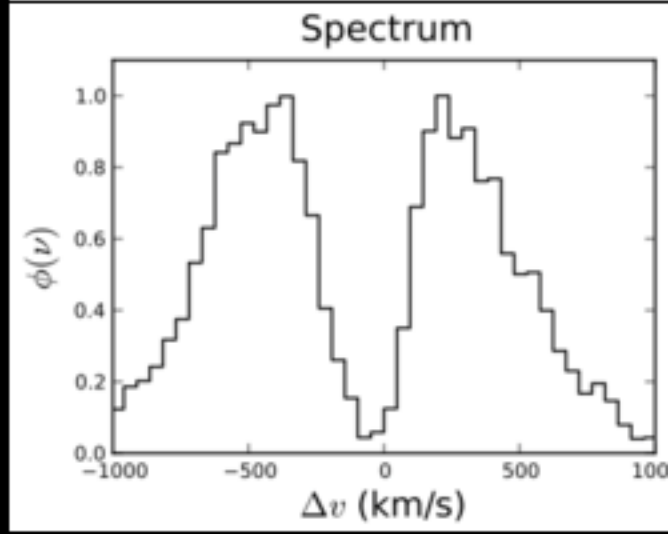
- At z~2, where cold streams covering factor << 1, absorption spectra are naturally dominated by wind signatures
- So it's okay that we haven't seen much trace of the cold mode yet

Lyα Emission

- Also computed Lyα emission from cold accretion, with ionizing + line RT (CAFG et al. 2010)
- Contrary to previous studies (without RT), find that pure cooling cannot explain the observed giant Lyα blobs, with $L_\alpha \sim 10^{44}$ erg s^{-1}:
  - ➡ Lyα luminosity too small
  - ➡ surface brightness too low
  - ➡ spectral shape inconsistent with outflow signatures in observed sources
- Most likely, giant LABs are manifestations of feedback processes
- Some fainter sources (e.g., Rauch et al. 2008) could be powered by cooling







The Way Forward

- 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; it won't be easy!
- 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 to pull out small covering factor cold streams
- We must start including winds and metals in our models