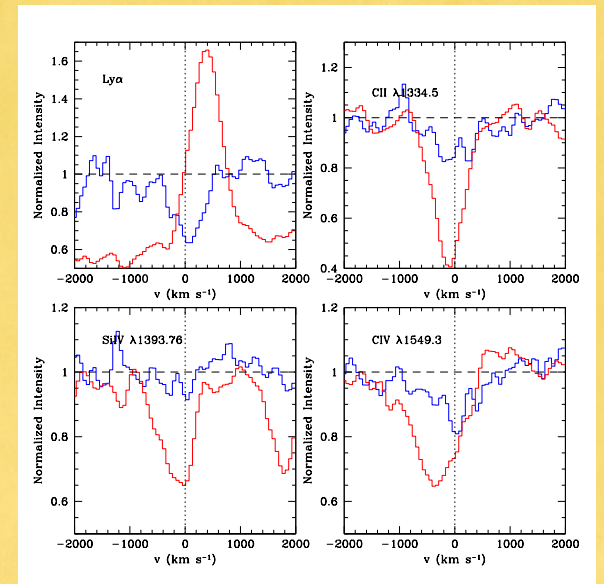
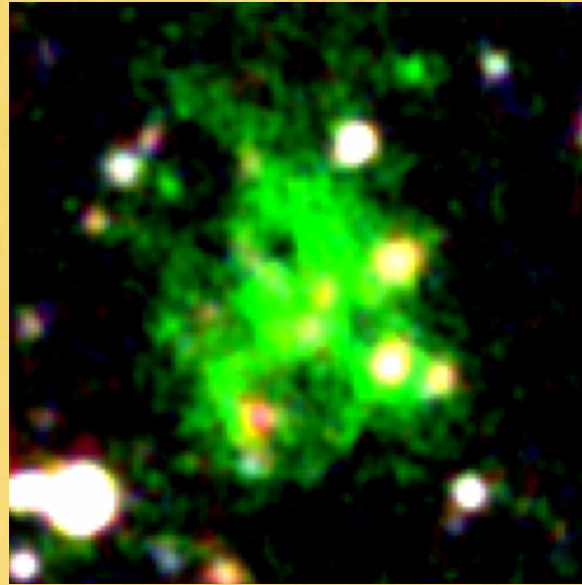
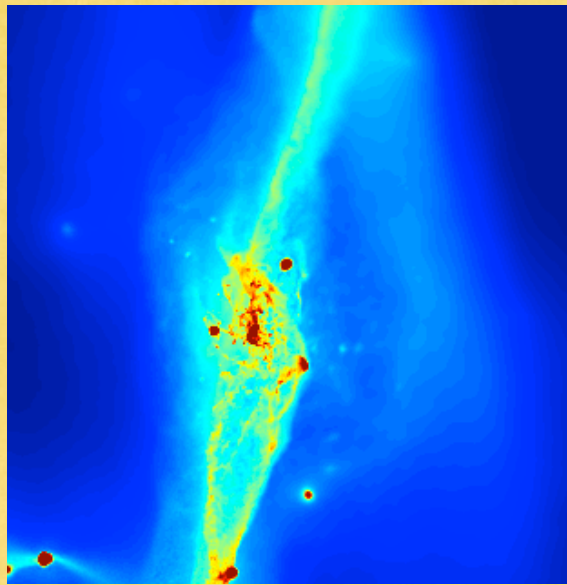


Modeling the Signatures of Galaxy Assembly



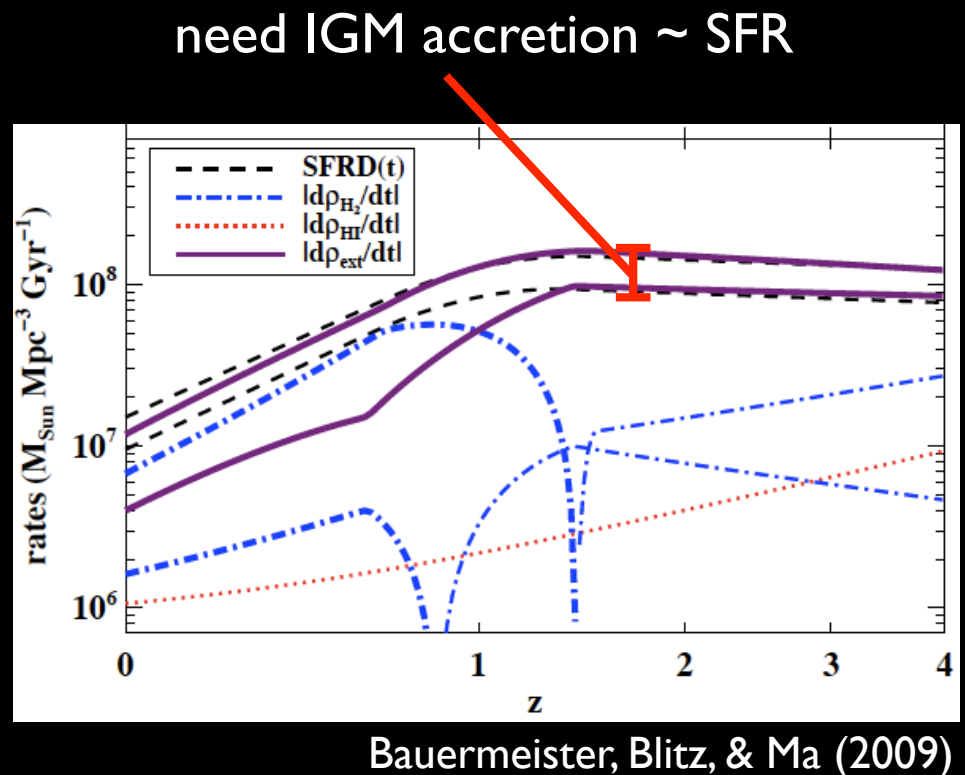
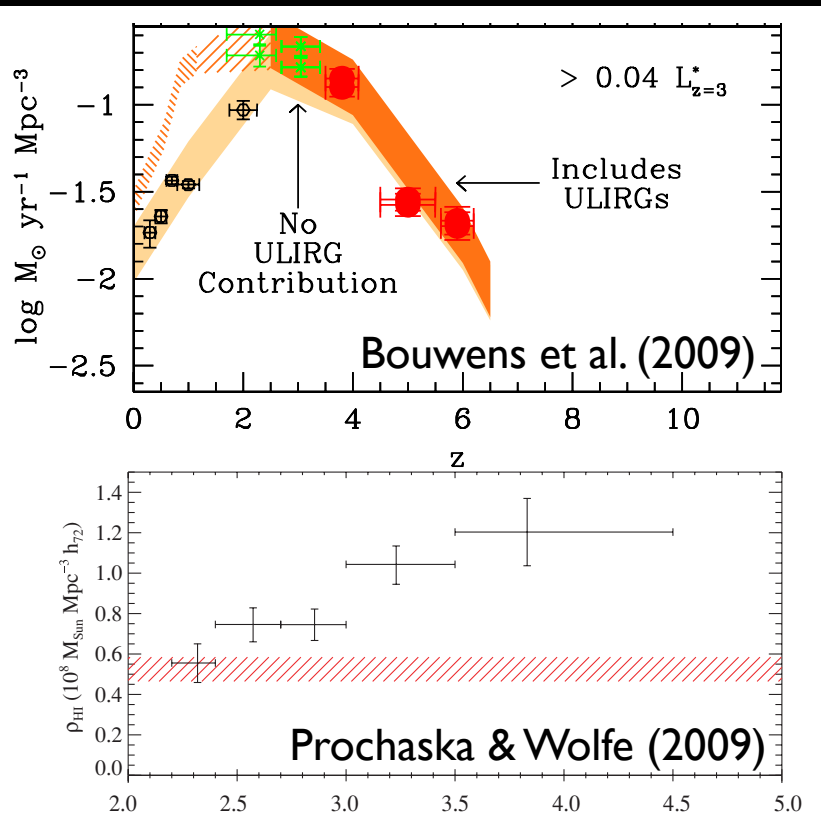
Claude-André Faucher-Giguère

UC Berkeley

Miller Institute for Basic Research in Science

The Need for Sustained Accretion

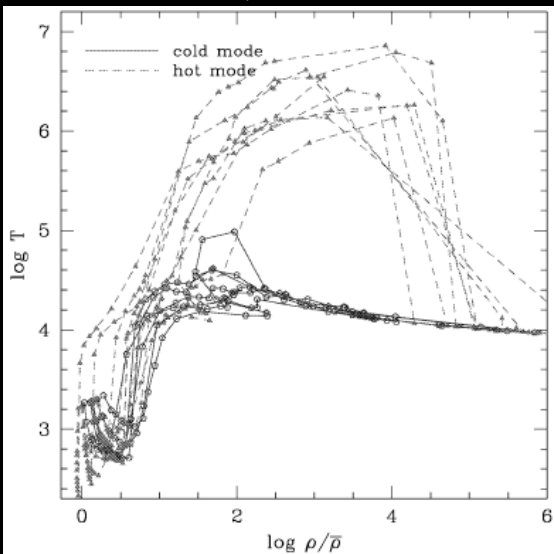
- Galaxies deplete their H_2 on time scale $\sim \text{Gyr} \ll t_H$
- Measured **HI reservoir vs. z is insufficient**
- Must be continuously **replenished by accretion** of ionized gas from the IGM!



Cold vs. Hot Modes

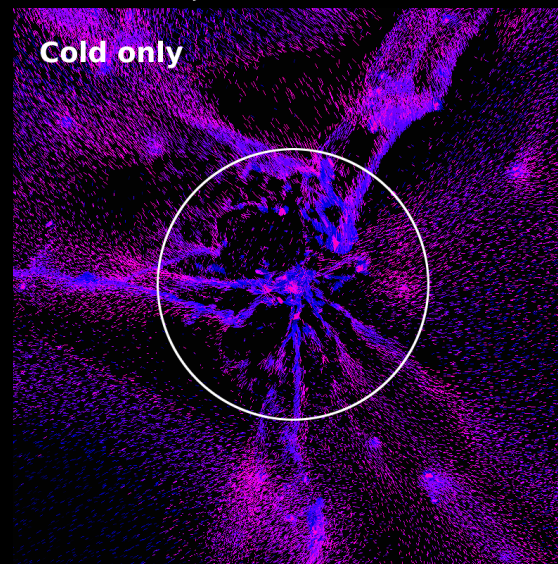
- Gas accretion is *predicted* to be bimodal:
 - ➔ **cold mode**: most accreted gas is never shock heated to T_{vir} and maintains $T < 2.5 \times 10^5$ K
 - ➔ **hot mode**: smaller fraction shock heats and cools as in classical picture
- Found in both SPH and AMR numerical simulations

T trajectories



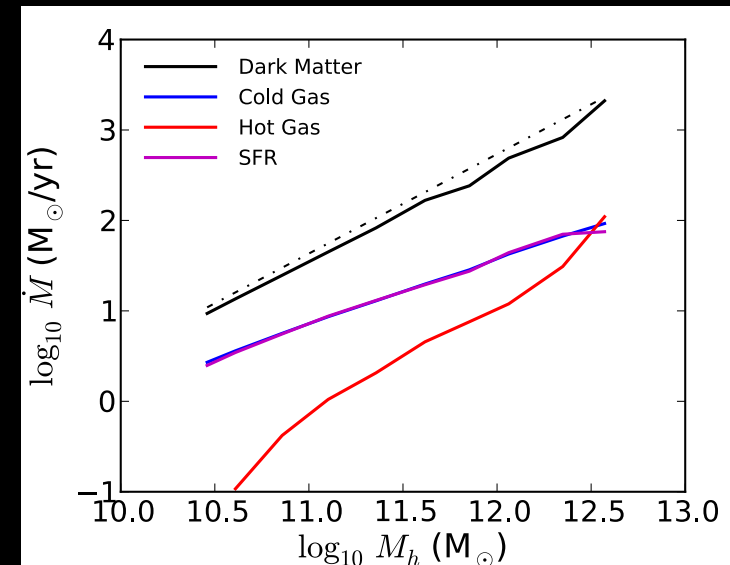
Kereš et al. (2005)

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



Kereš et al. (2009)

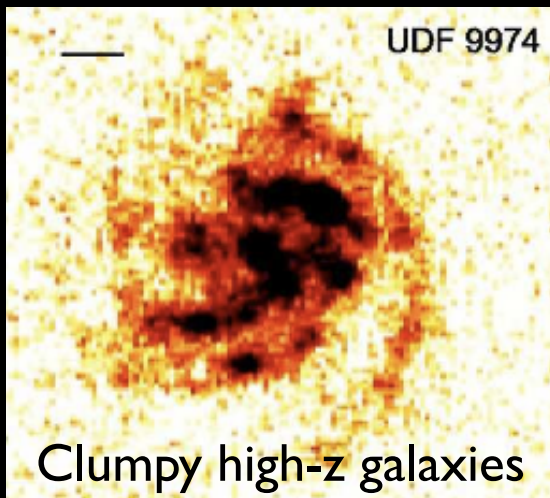
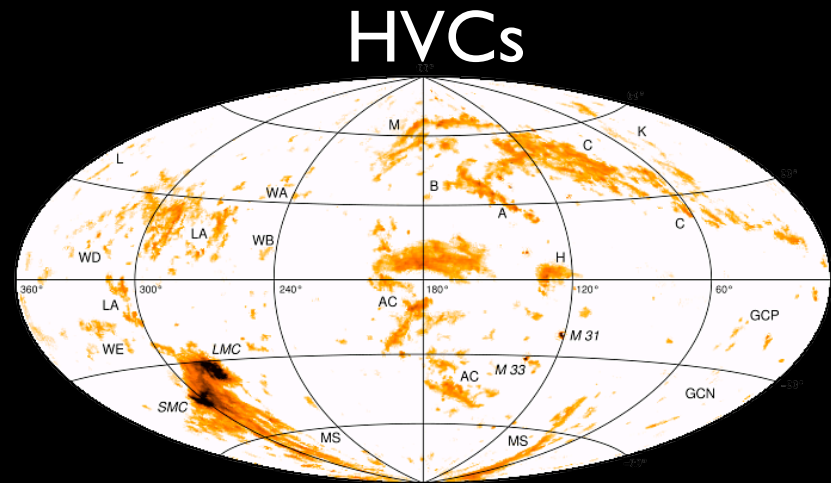
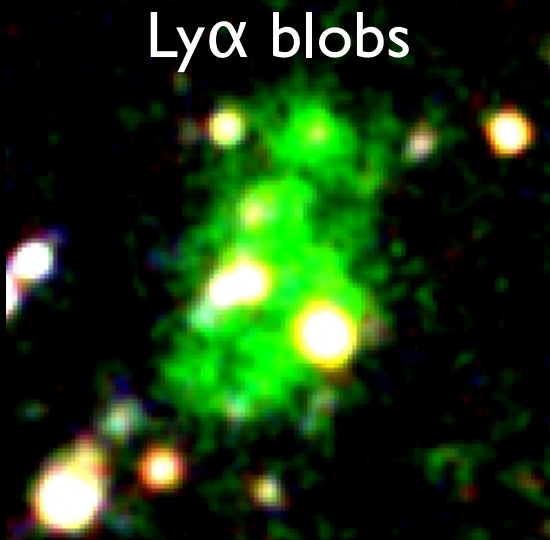
Halo accretion rates vs. $M_h, z=3$



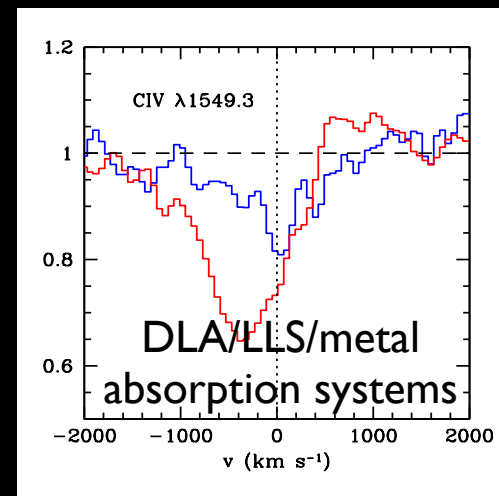
CAFG, Kereš, Ma, in prep.

Connections to Observed Phenomena?

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



Clumpy high-z galaxies



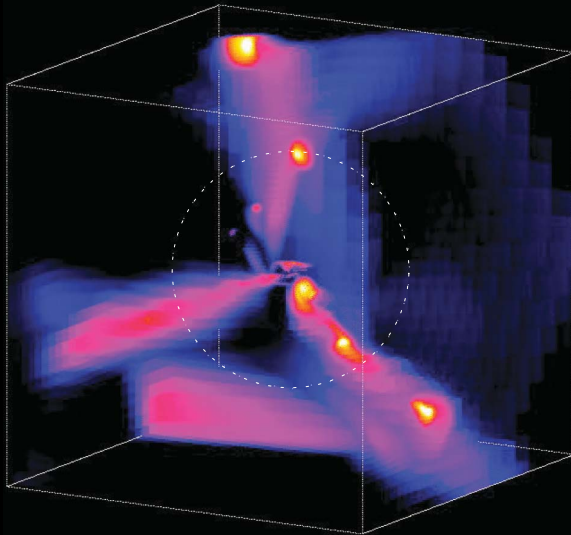
- *But, are they?*

Observational Puzzle

- So far, **little trace of infalling cool material around $z \sim 2-3$ 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

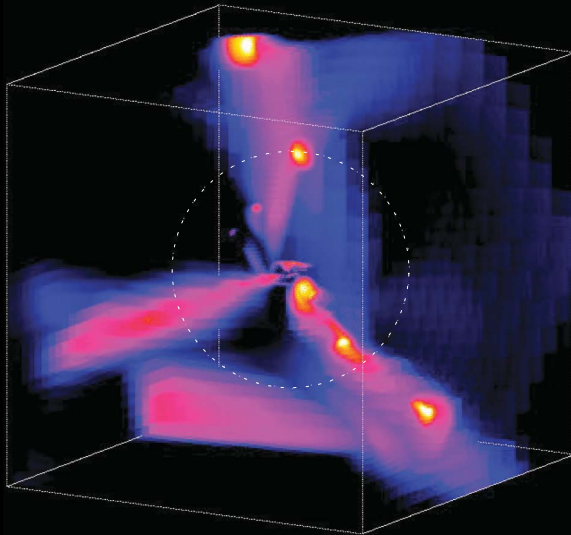
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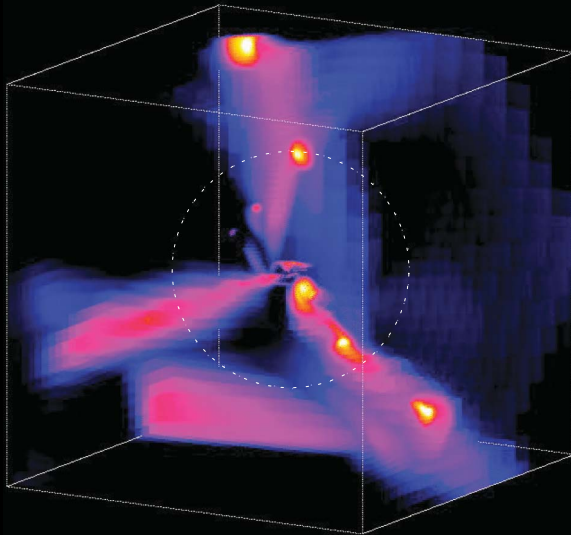
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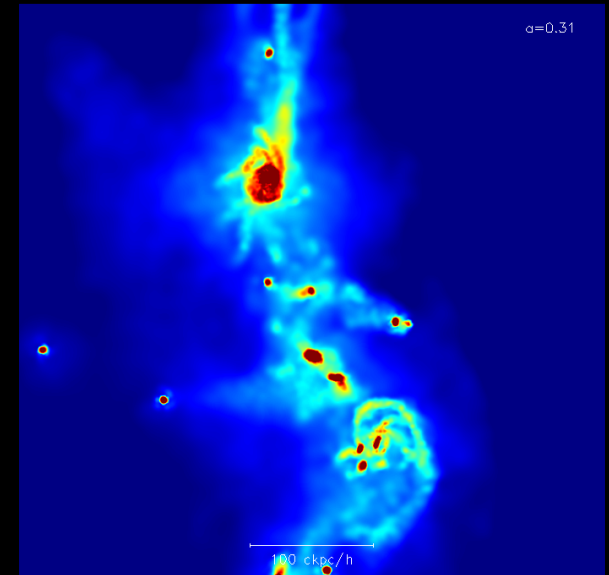
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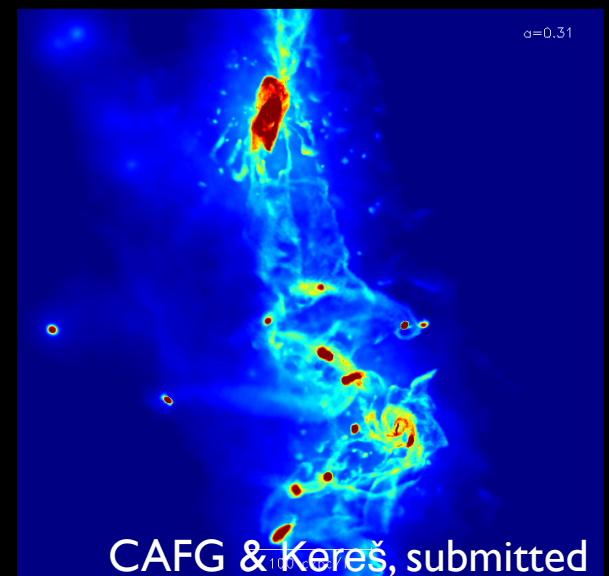
Theoretical Issues

- 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 Ly α emission, look at simplified problem of pure accretion in Λ CDM

$10^6 M_{\odot}$ res.



27x better

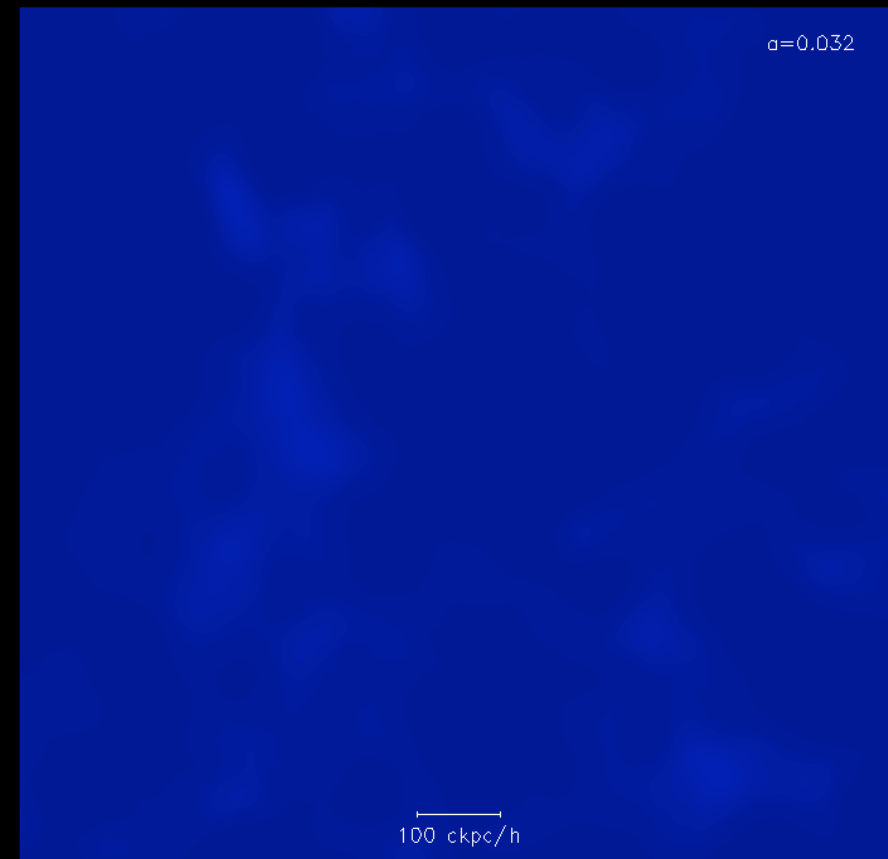


Numerical Setup

- **Zoom-in** simulations for very high resolution
 - ➔ 27 proper pc gas smoothing length achieved at $z=2$
 - ➔ $\epsilon=275$ comoving pc/h Plummer equivalent gravity
- **Milky Way progenitor, LBG at $z\sim 2-3$**
- Ionizing RT
 - ➔ UV background
 - ➔ local sources
- Lower-resolution runs to check convergence, variance

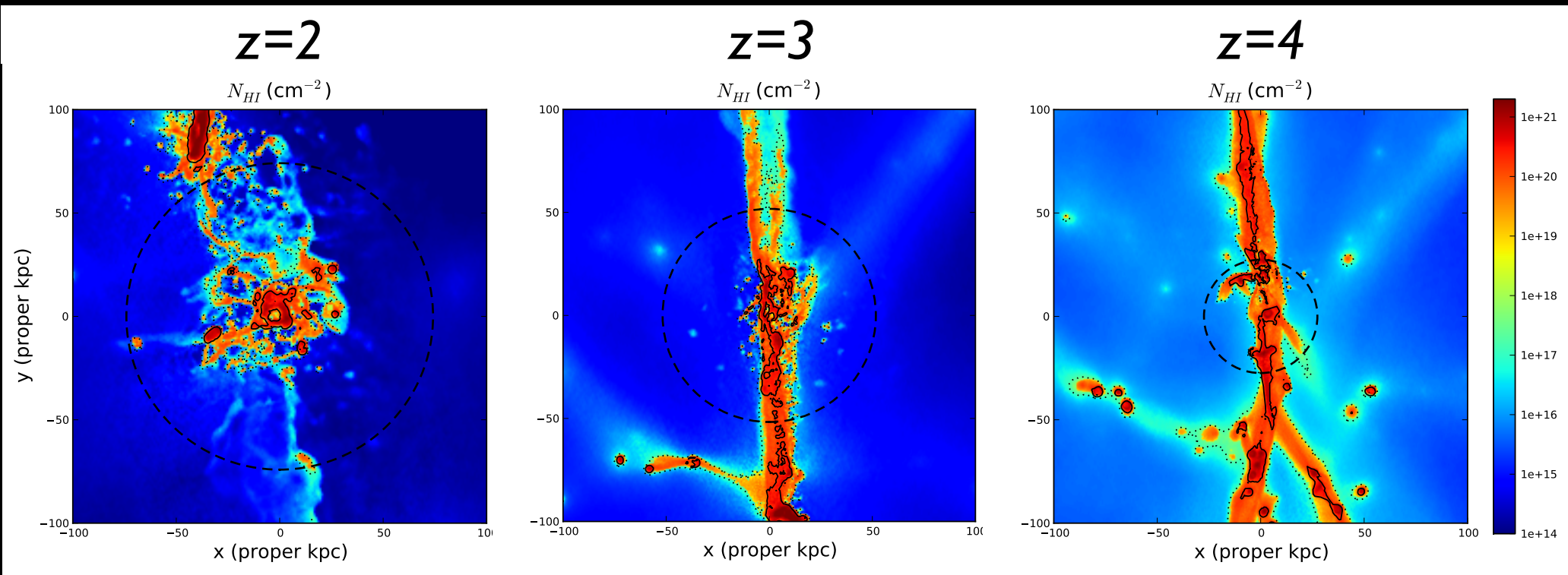
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CAFG & Kereš, submitted

HI Stream Covering Factor



CAFG & Kereš, submitted

Within $1 R_{vir}$

LLS: 11%

15%

30%

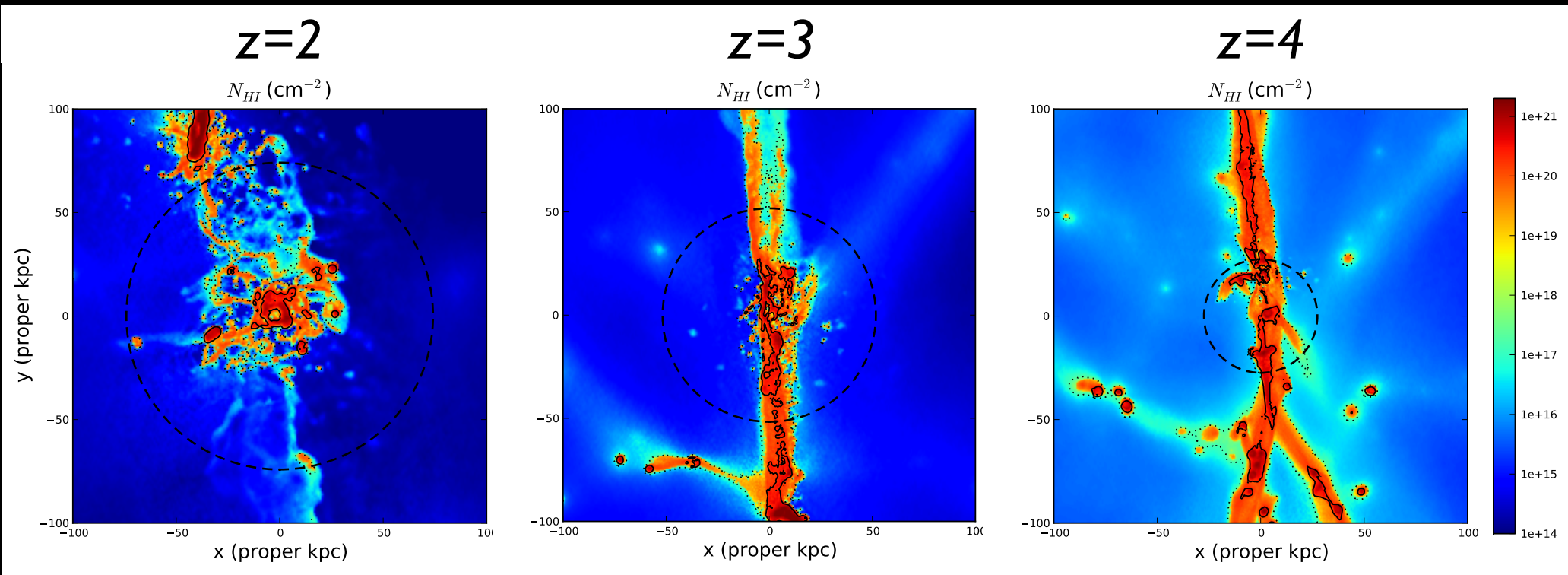
DLA: 2%

5%

9%

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

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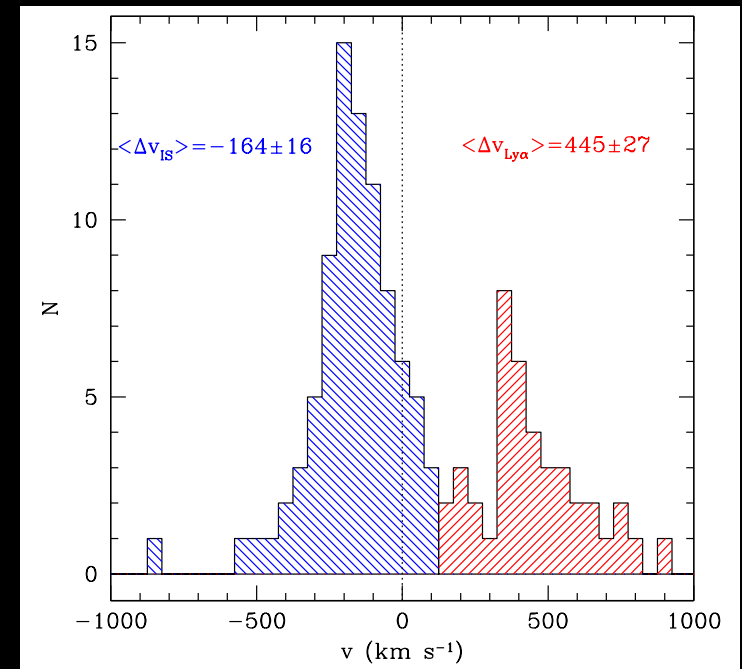
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Compare with Winds

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

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

\Rightarrow winds with ~ 1 covering factor

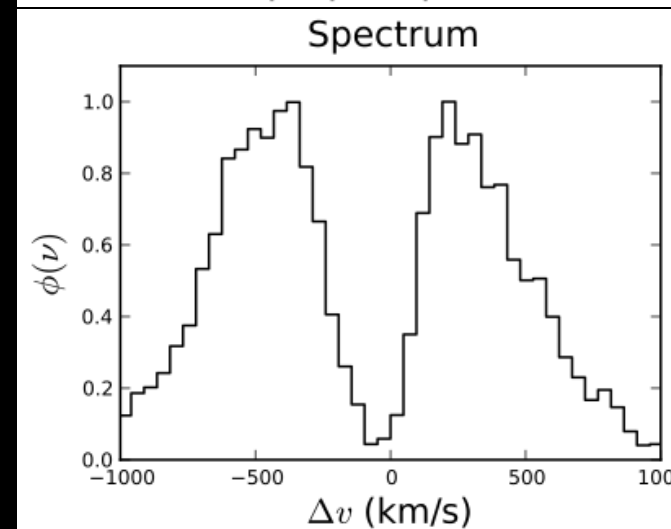
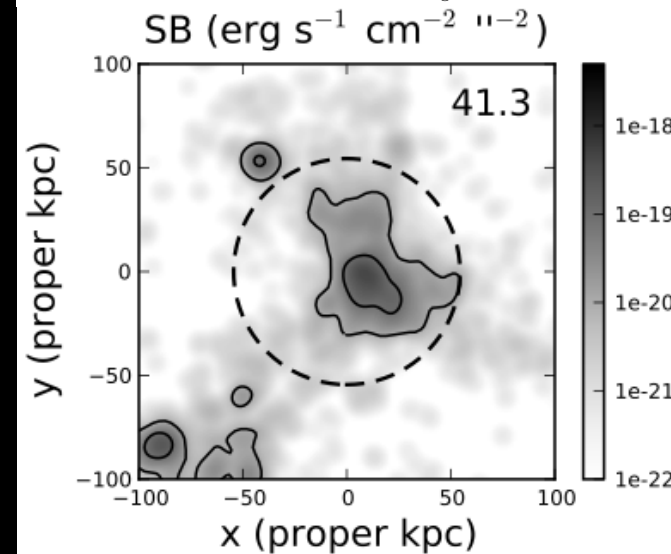
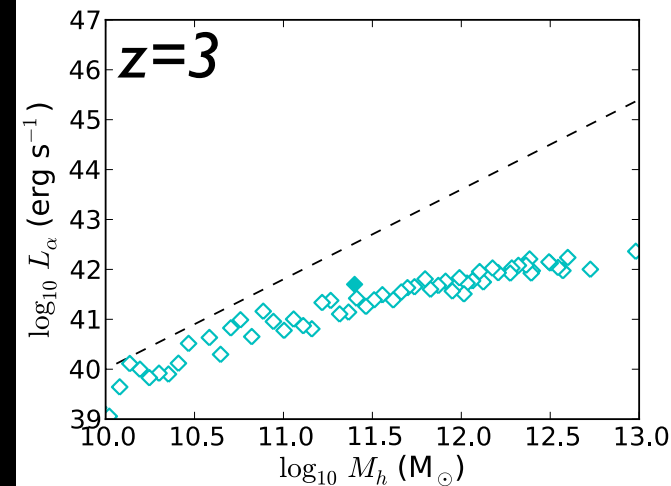


Steidel et al. (2010)

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

Ly α Emission

- Also computed **Ly α 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 Ly α blobs**, with $L_{\alpha} \sim 10^{44}$ erg s $^{-1}$:
 - ➔ Ly α 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 Ly α 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 $v \sim v_{\text{circ}}$ vs. outflows up to ~ 800 km/s)
 - ➔ **metallicity** (expect $Z_{\text{infall}} < Z_{\text{wind}}$, 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**