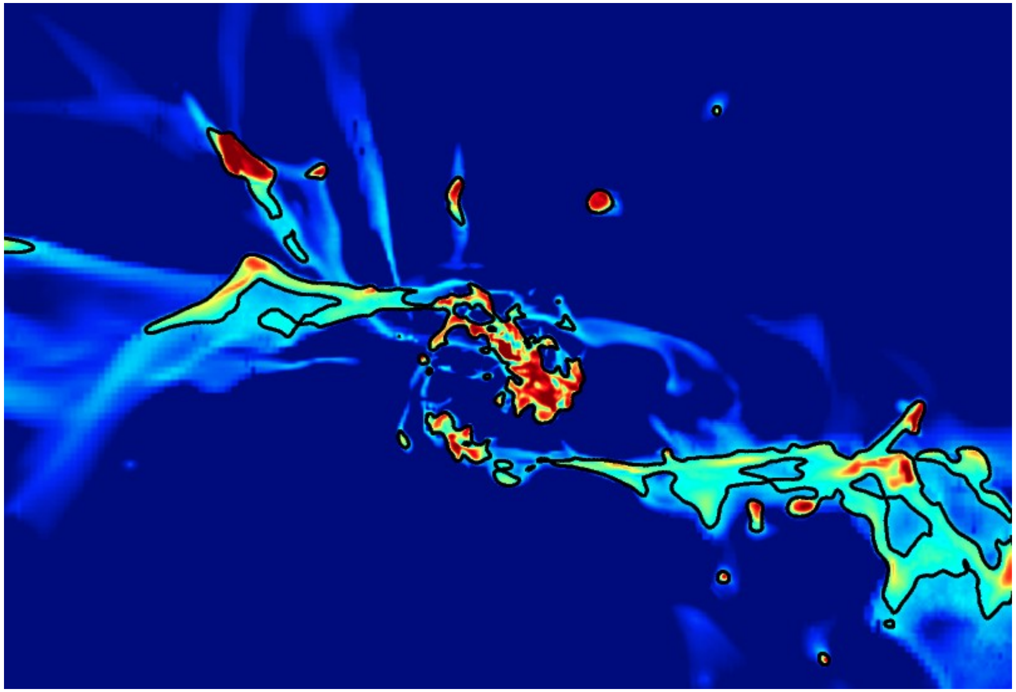
Detecting cold streams with absorption line systems



Michele Fumagalli

Inter[stellar and galactic] Medium Program of Studies (IMPS) at UC Santa Cruz

In collaborations with:

Xavier Prochaska, Daniel Kasen, Avishai Dekel, Daniel Ceverino, Joel Primack and John O'Meara

Fumagalli et al., 2011, MNRAS (arXiv:1103.2130)

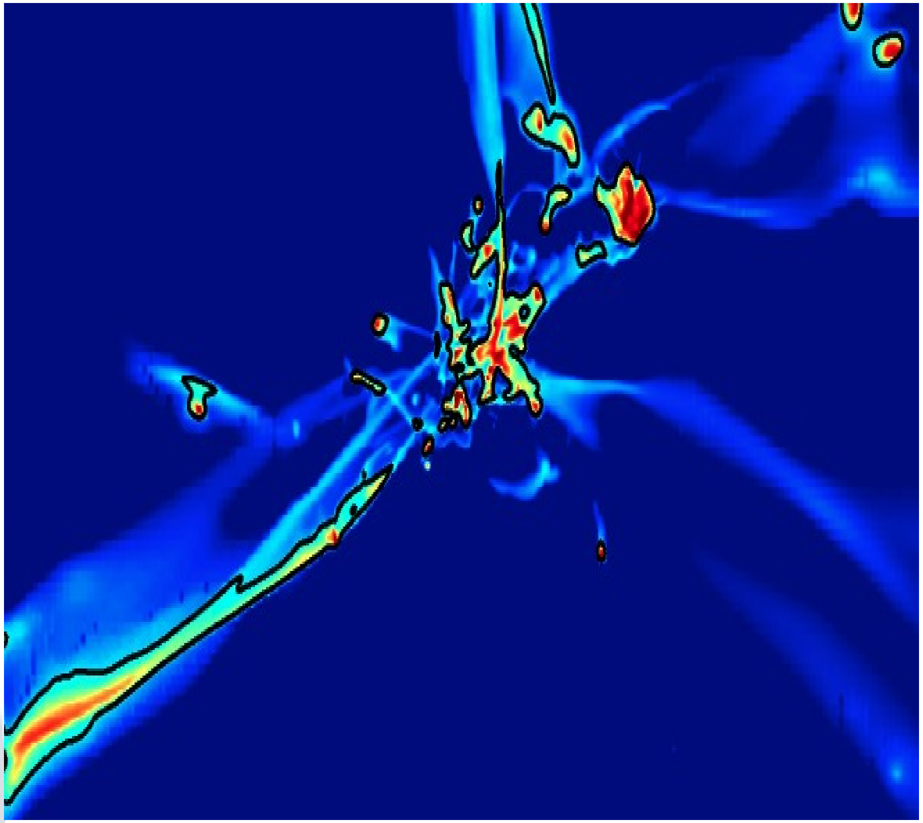
Santa Cruz galaxy workshop 2011

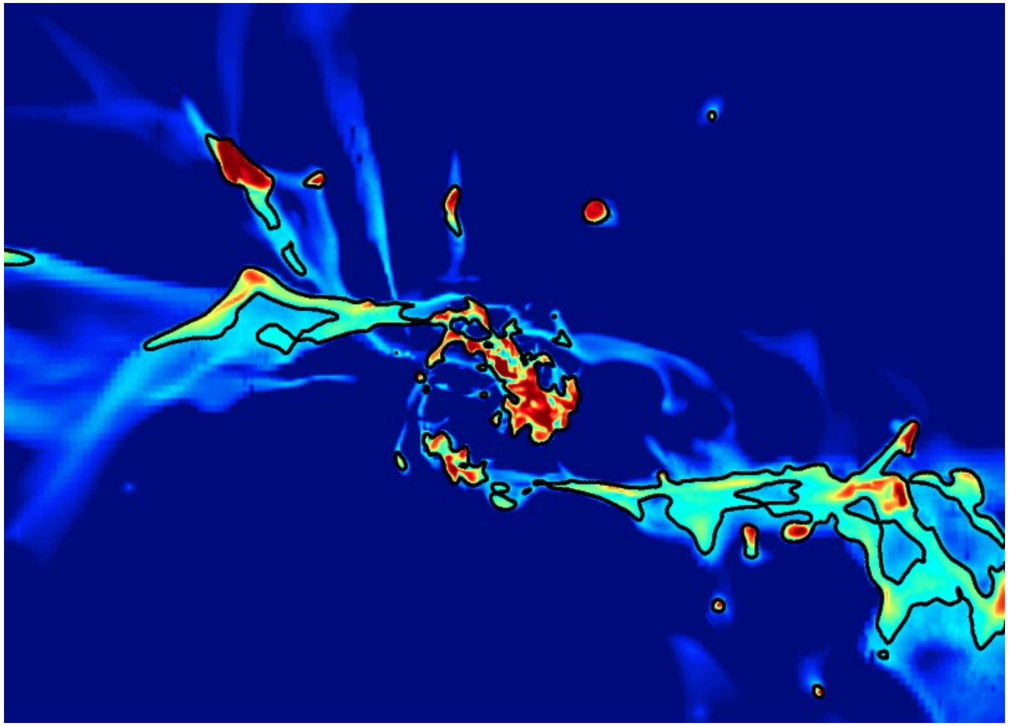
8-12 August 2011 - UCSC

Predictions of cold accretion

Simulations predict that cold gas (< 10^5 K) in narrow streams and satellites is the dominant source of fresh fuel for star formation at high-z

(Katz et al., 2003; Kereš et al., 2005,2009; Dekel&Birnboim,2006; Dekel et al.,2009; Faucher-Giguère et al.,2011)



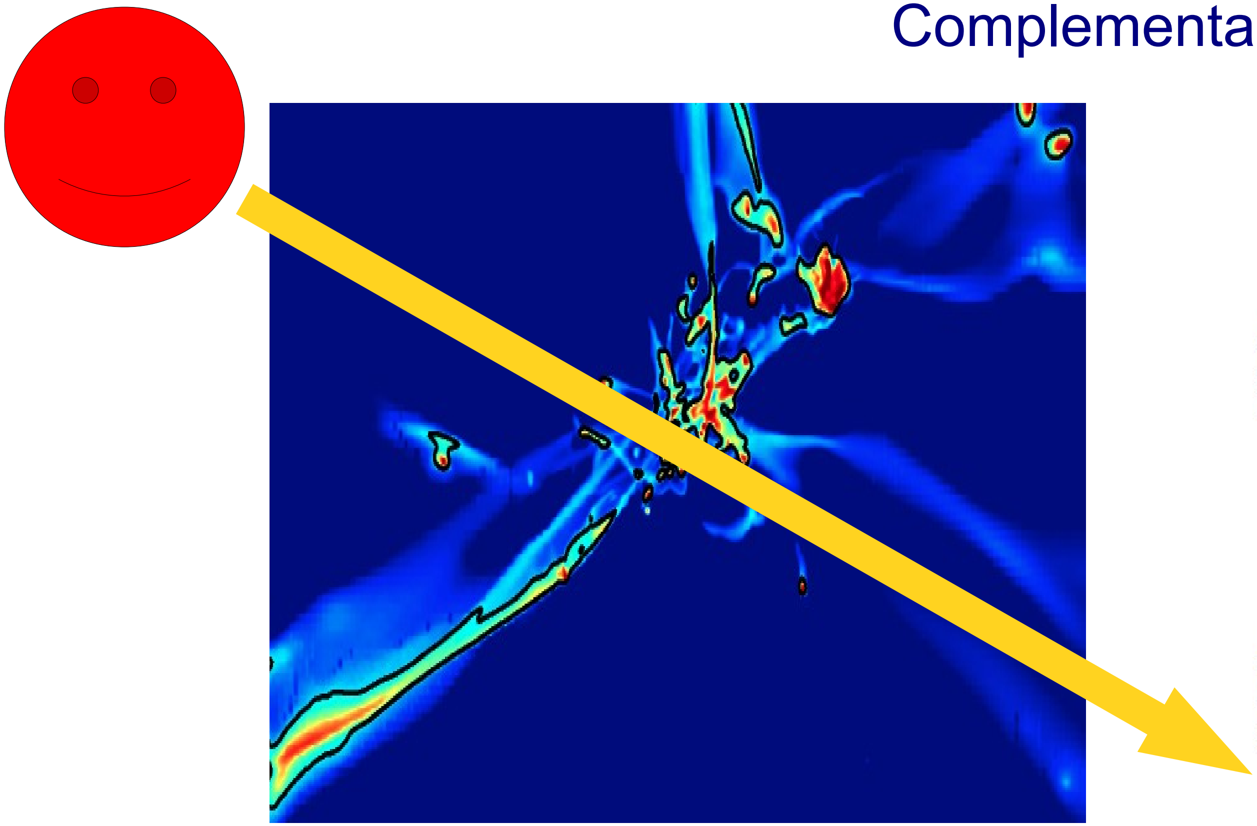


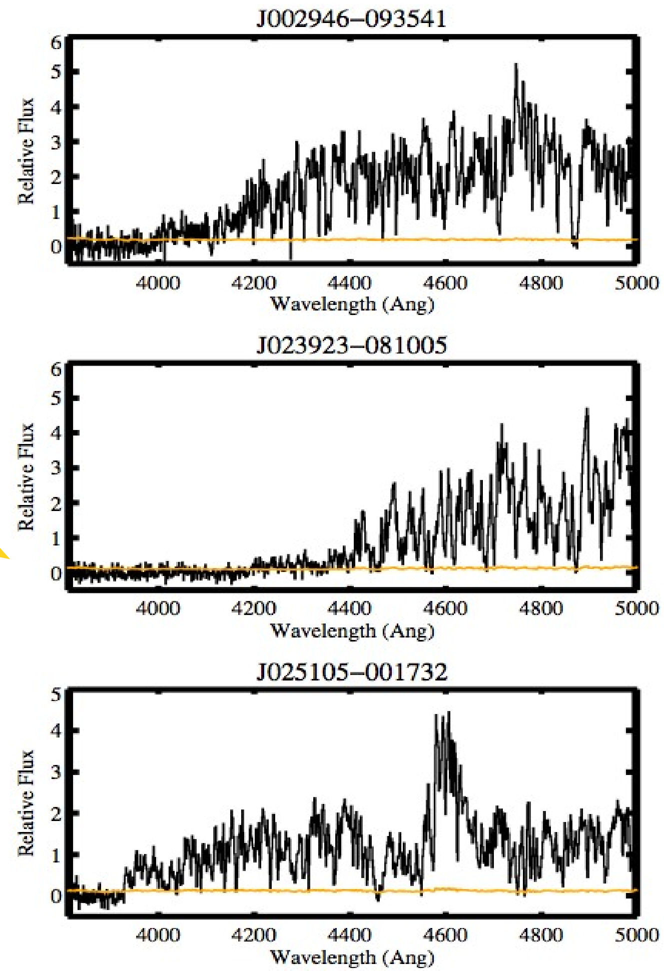
Evidence of cold streams...

+ Katz and many others....

...with absorption line systems

Complementary to Lyα in emission





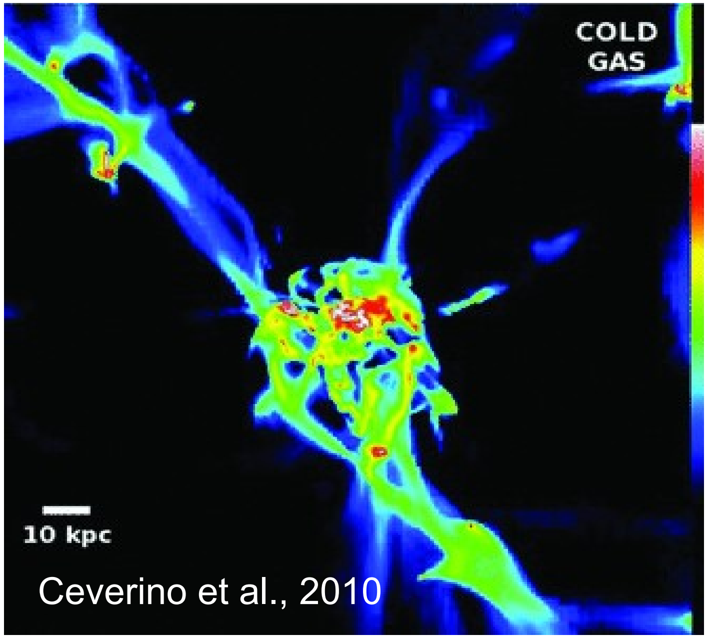
We need predictions on how cold streams look like as seen in absorption

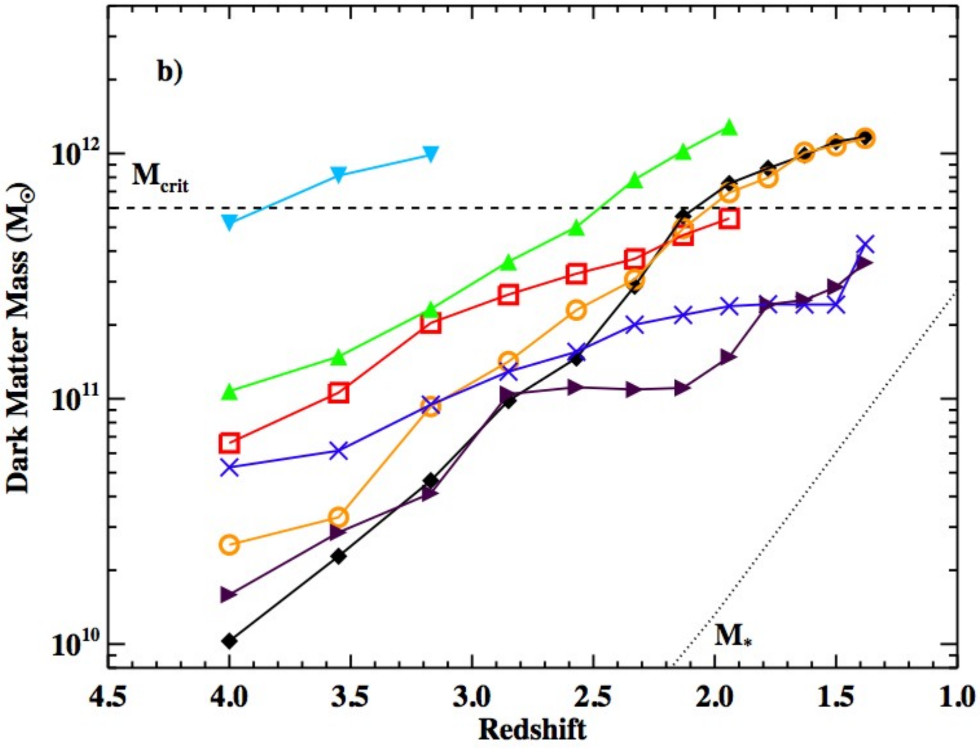
(Stewart et al. 2010; Faucher-Giguère & Kerěs 2011; Kimm et al, 2011; MF et al., 2011; Rubin et al., 2011)

Numerical simulations

We use high resolution (35-70 pc) AMR cosmological hydrodynamical simulations (Ceverino et al., 2009; 2010) using the ART code

(Kravtsov, Klypin & Khokhlov 1997; Kravtsov 2003)





Stellar feedback is implemented and gives rise to outflows of hot gas with velocities of few hundreds km/s. The outflow mass flux is up to 1/3 of the inflow one.

Radiative transfer post-processing

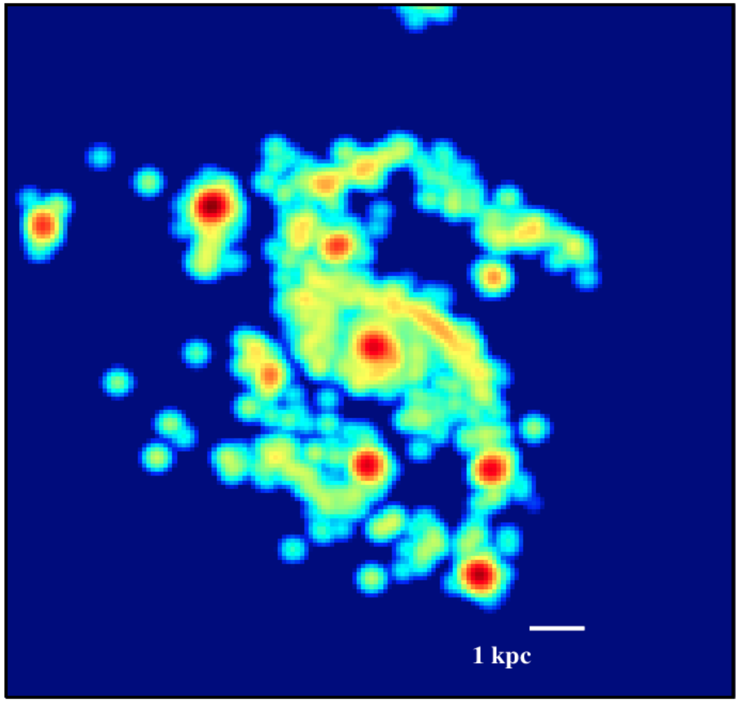
Sensible estimates of the neutral hydrogen require radiative transfer

(e.g. Faucher-Giguère & Kerěs 2011; Altay et al., 2010; McQuinn et al., 2011)

The Monte Carlo RT code includes:

- Collisional ionization
- UV background
- Stellar radiation
- Dust scattering and absorption

(Kasen et al., 2006;2011)



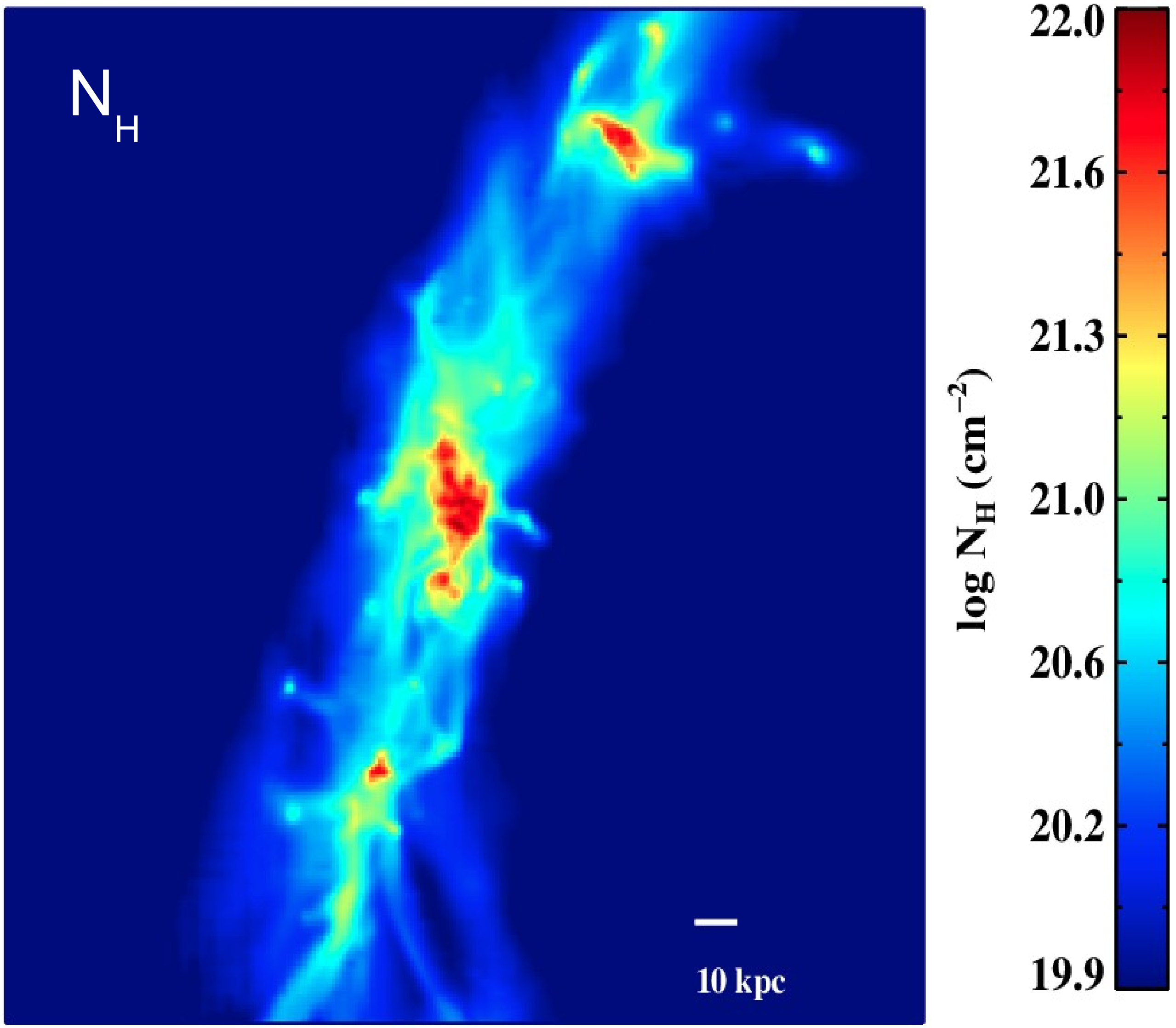
We obtain ≤ 10% escape fraction at the virial radius

Local sources matter

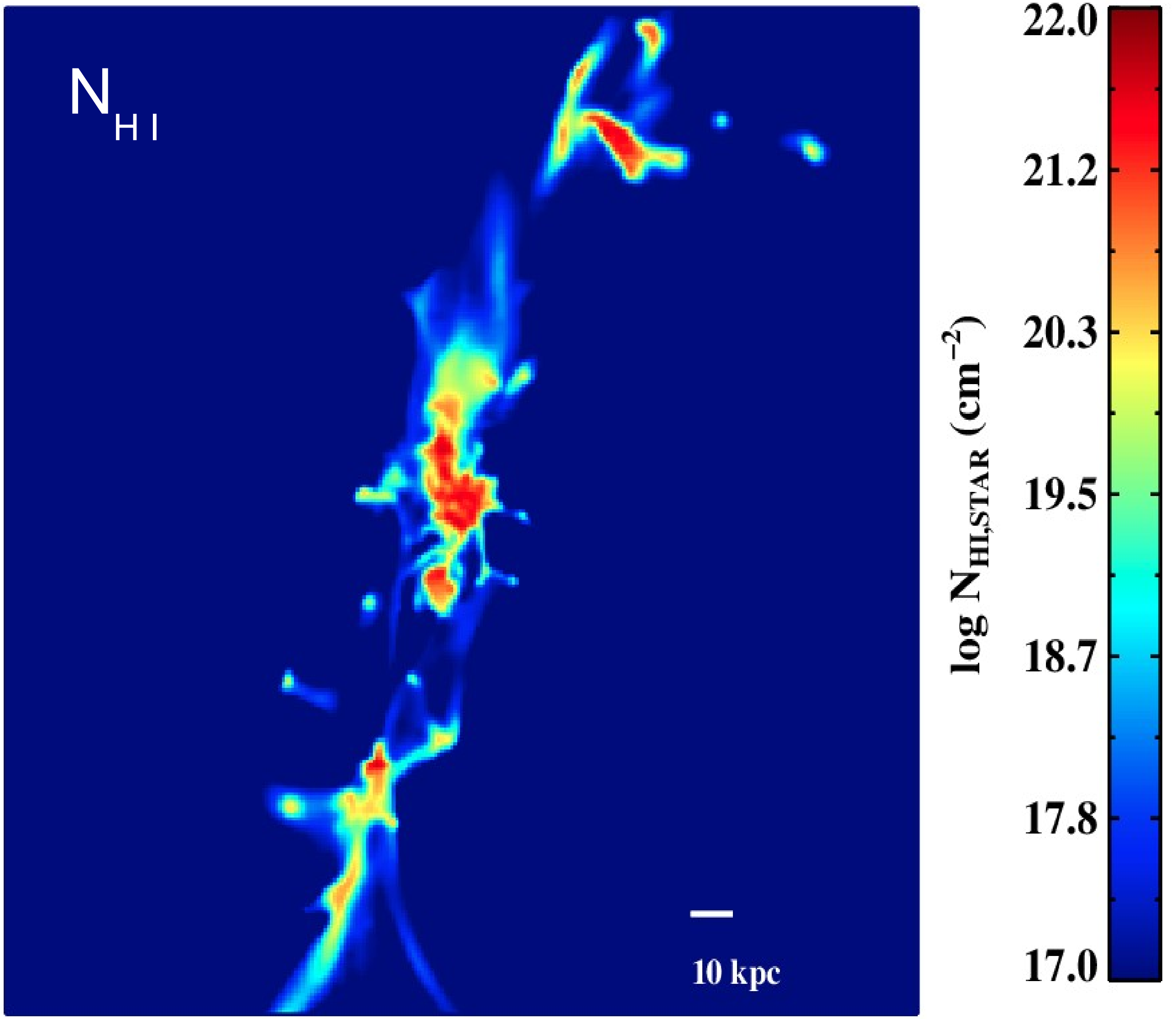
How cold streams look like:

- Cold streams are mostly ionized
- The covering factor is below 25% at all redshifts
- Cold streams contribute to the LLS population
- Cold streams are metal poor ($Z \sim 1\% \ Z_{sun}$)
- Cold streams exhibit moderate kinematics

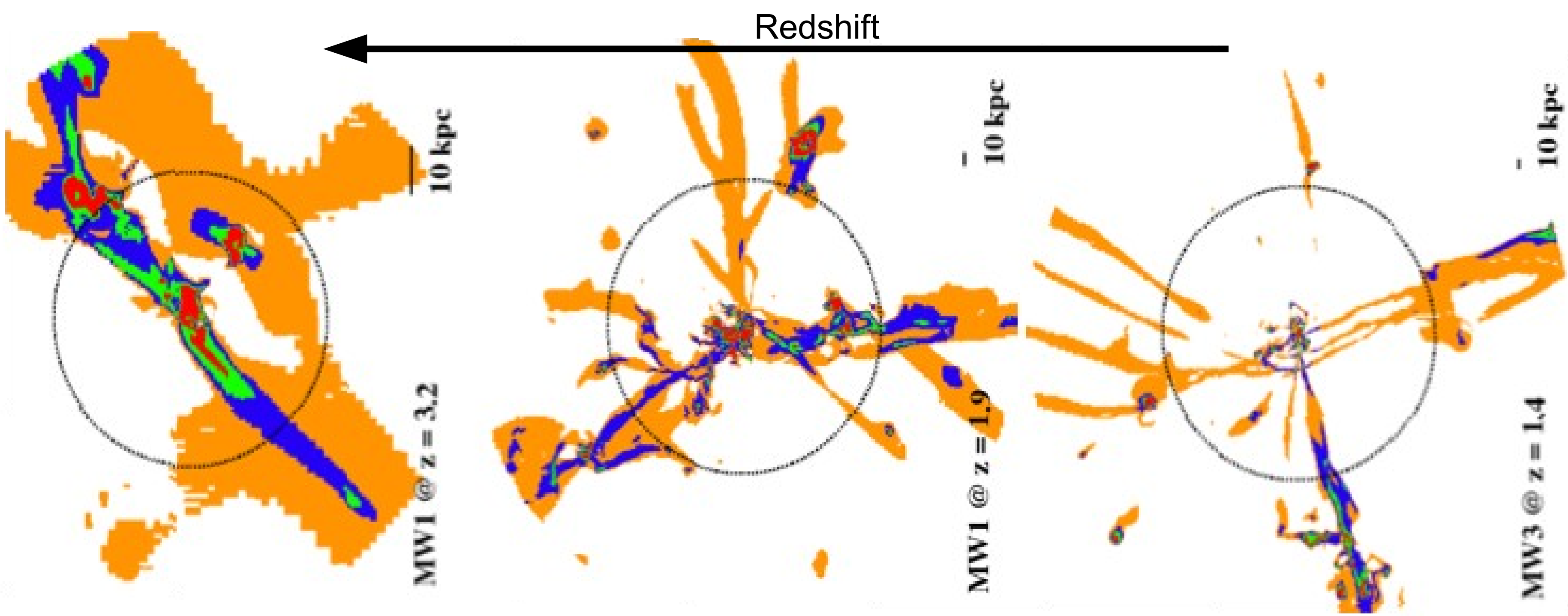
1) Cold streams are ionized



1) Cold streams are ionized



2) The covering factor is < 25 %



At R_{vir}, the covering factor is:

- Optically thin gas 20 - 60%
- Ionized gas (LLS) 6 - 25%
- Galactic neutral gas 1 - 5%

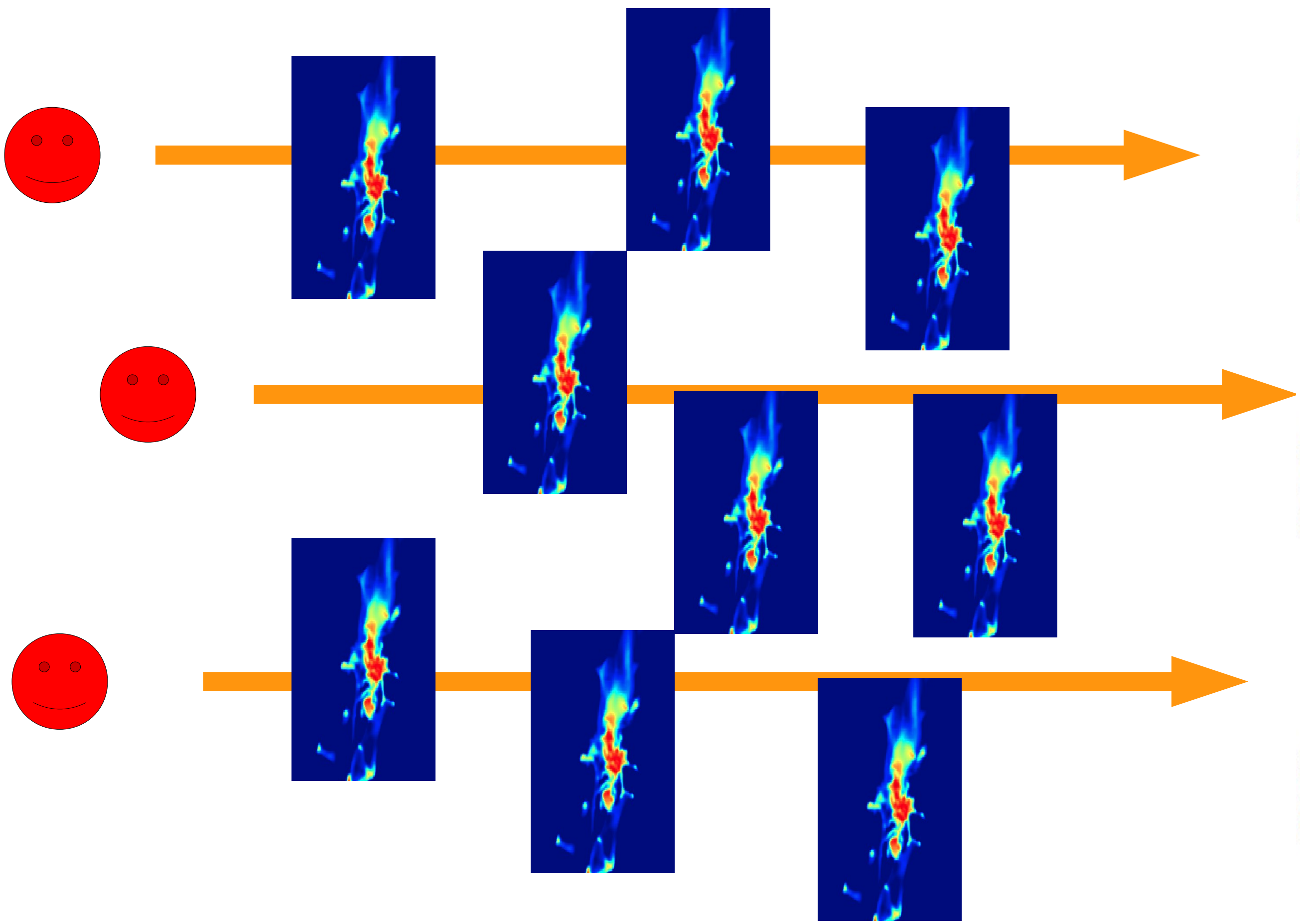
(e.g. Dekel et al., 2009; Kerěs & Hernquist 2009; Stewart et al. 2010; Faucher-Giguère & Kerěs 2011)

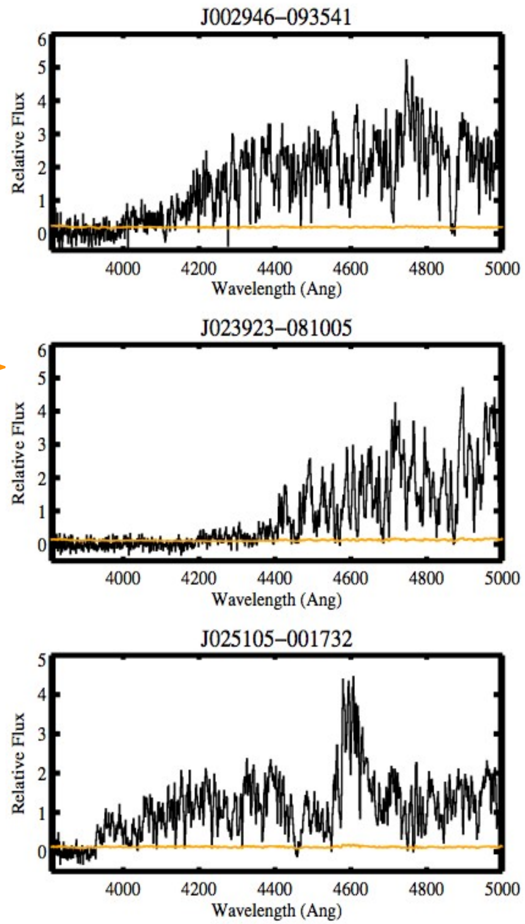
... but ...

3) The incidence is > 30%

Surveys of systems in foreground of quasars probe the cross section and number density of absorbers, not just the covering factor.

(e.g. Péroux et al., 2003; O'Meara et al., 2007; Noterdaeme et al., 2009; Prochaska et al., 2010)

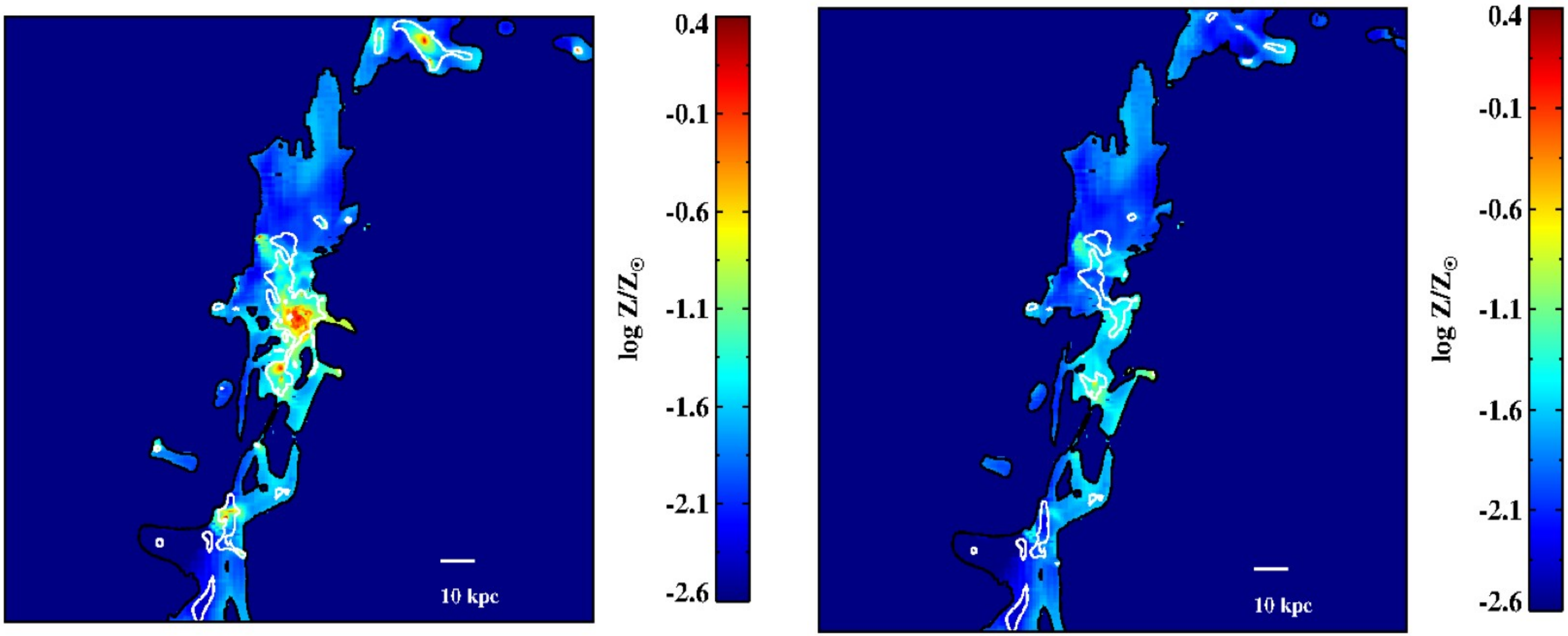




(cfr. Razoumov+2006; Nagamine+ 2007; Pontzen+ 2008; Tescari+ 2009; Cen+ 2010; Altay+2010; McQuinn+ 2011)

4) Streams are metal poor

Cold streams are metal poor (1% solar), albeit non primordial.



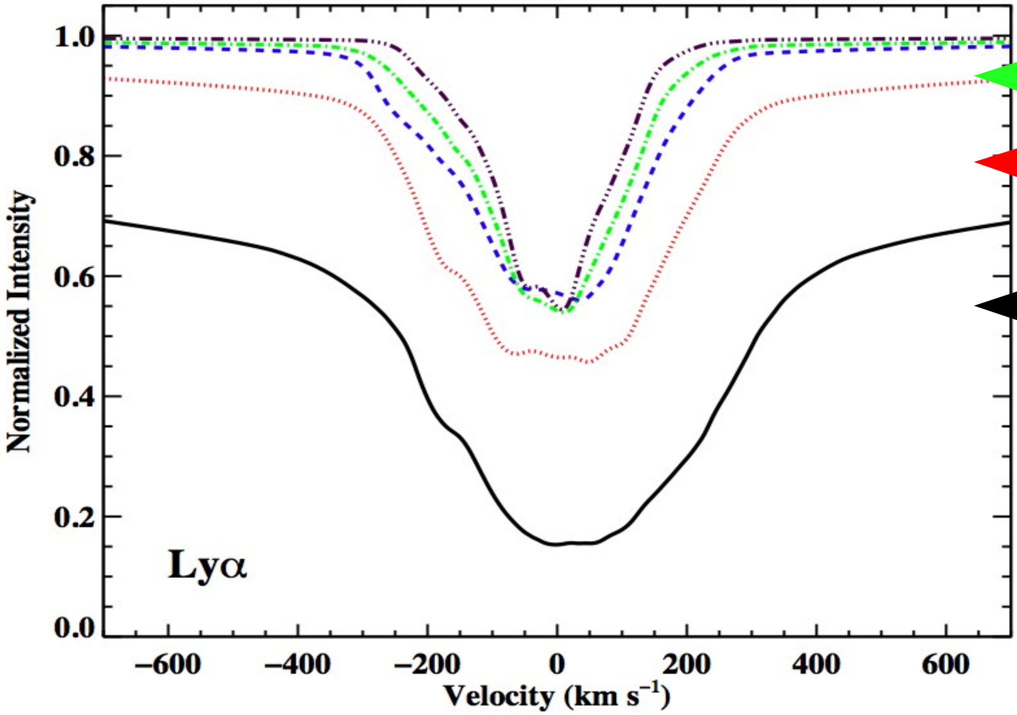
- The low metal content of cold streams is a key element to separate them from the more metal rich gas in outflows.

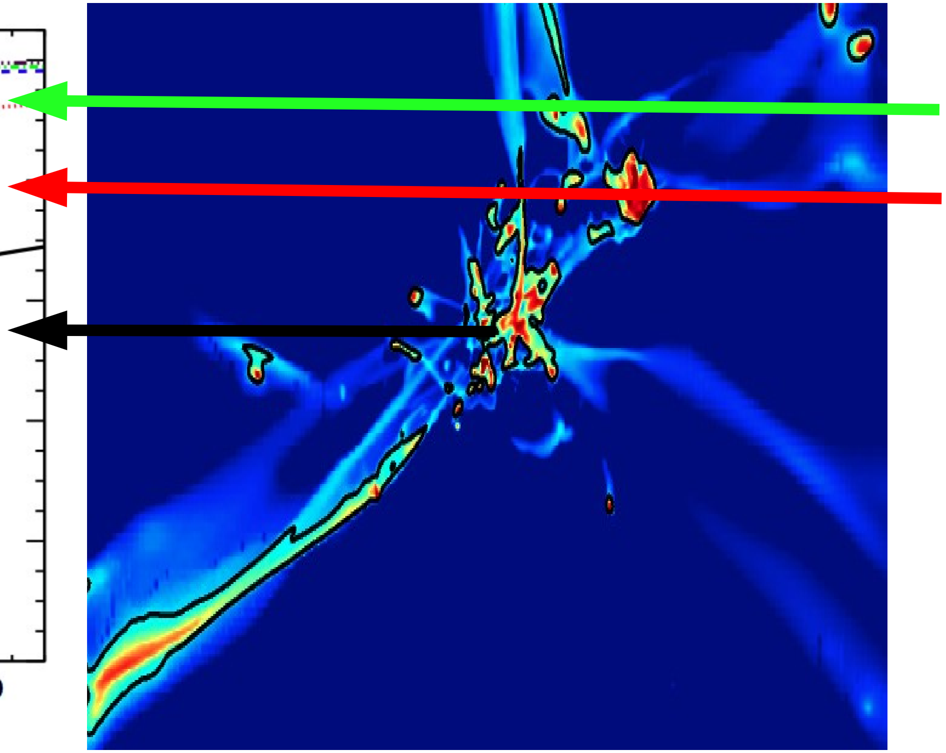
(Prochaska et al., 1999; Cooksey et al., 2008; Kacprzak et al., 2010; Kimm et al., 2011;Ribaudo et al., 2011)

5) Kinematics are moderate

Simulations with cold streams reproduce the observed kinematics of Lyα but underpredict the strength of low ionization metal lines

(cf. Steidel et al., 2010; Powell et al., 2010; Kimm et al., 2011)

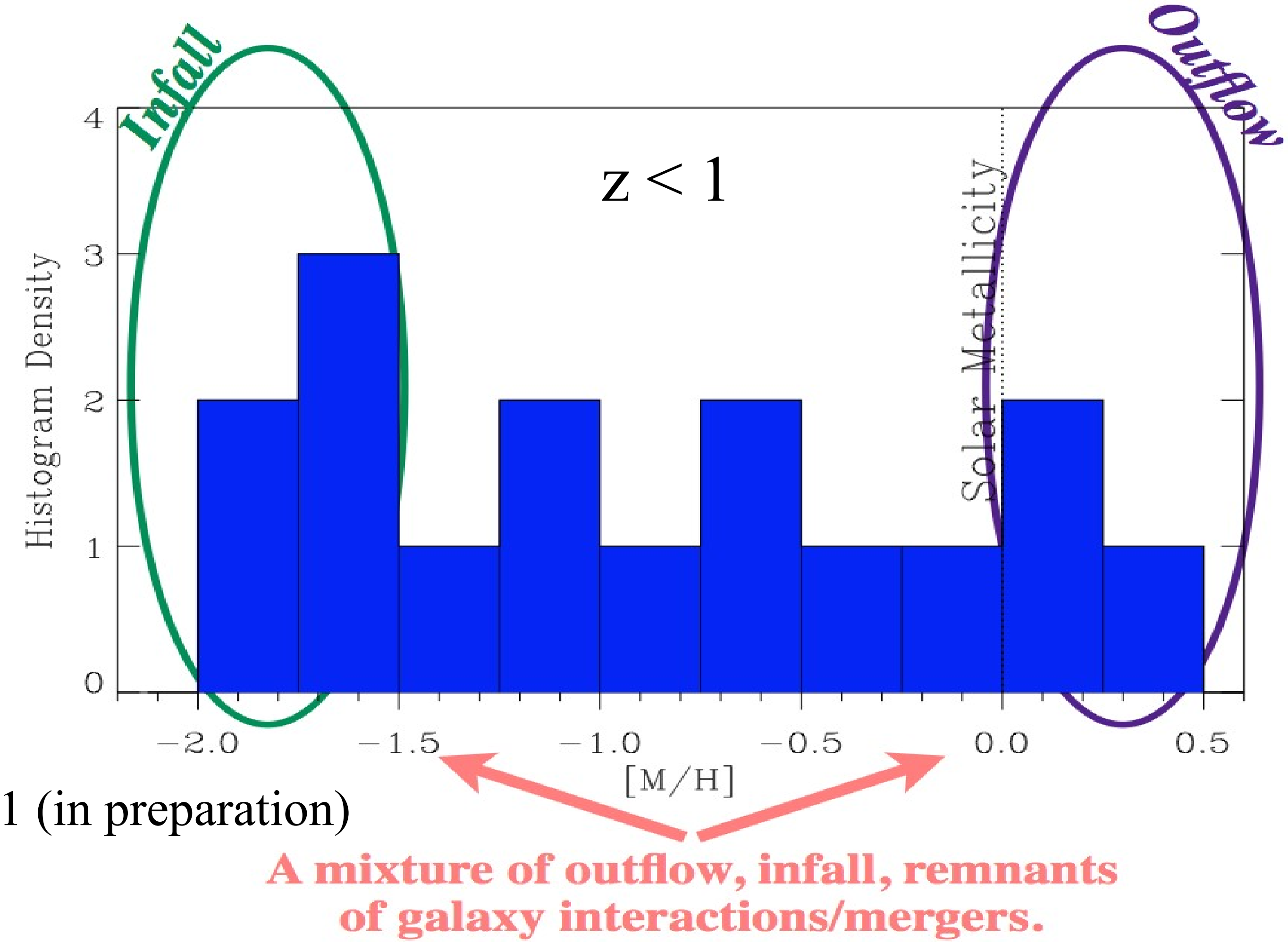




Are similar systems observed?

While the population of LLSs is likely to trace gas in a variety of phases, the discovery of metal poor LLSs could be the first detection of cold streams

(e.g. Prochaska et al., 1999; Tripp et al., 2005; Cooksey et al., 2008; Thom et al., 2011; Ribaudo et al., 2011)



Lehner+2011 (in preparation)

Current and future directions

Prospects to reveal the cold mode of accretion are good

Observational work should provide:

- The fraction of metal poor and metal rich LLSs
- Samples of galaxy-absorber pairs

Future work with simulations should characterize:

- How cold flows and outflows coexist and interact
- The kinematics and incidence of low and high ionization metal lines

Metal poor gas can be common at z~3, in line with model predictions