Detecting cold streams with absorption line systems

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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 Ly$\alpha$ 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 & Kerēs 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 $\leq 10\%$ 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 \((Z \sim 1\% \ Z_{\text{sun}})\)
- Cold streams exhibit moderate kinematics
1) Cold streams are ionized

\[ N_{\text{HI}} \]

\[ \log N_{\text{HI}} \text{ (cm}^{-2}) \]

10 kpc
1) Cold streams are ionized
2) The covering factor is $< 25 \%$

At $R_{\text{vir}}$, 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; Kerēs & Hernquist 2009; Stewart et al. 2010; Faucher-Giguère & Kerēs 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)
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 Ly$\alpha$ 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)

A mixture of outflow, infall, remnants of galaxy interactions/mergers.
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