Where are the baryons?
constraints from absorption line studies

Celine Peroux (Laboratoire Astronomique de Marseille)

Overview

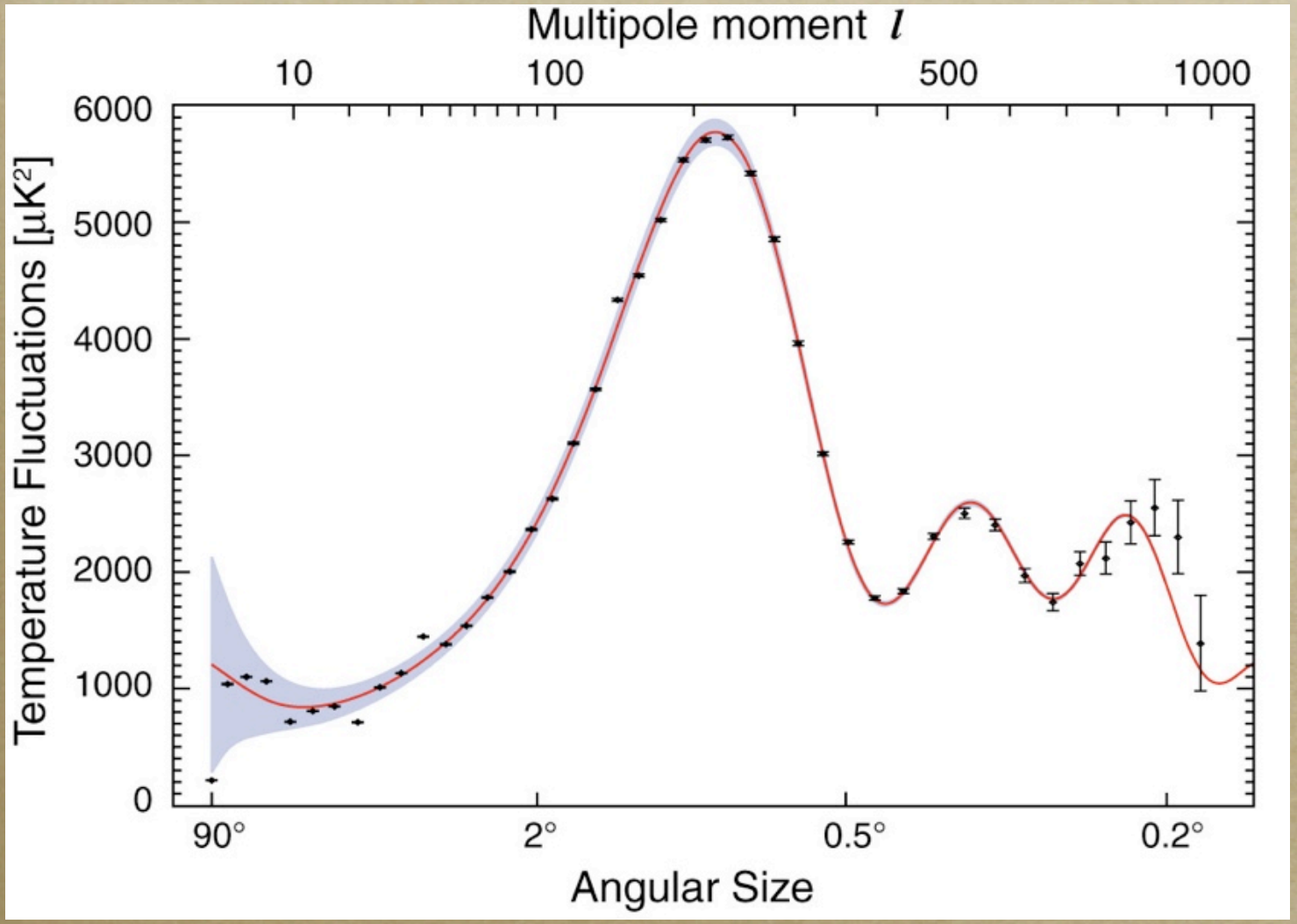
- the hidden baryons problem

- intergalactic medium/galaxy co-evolution

Overview

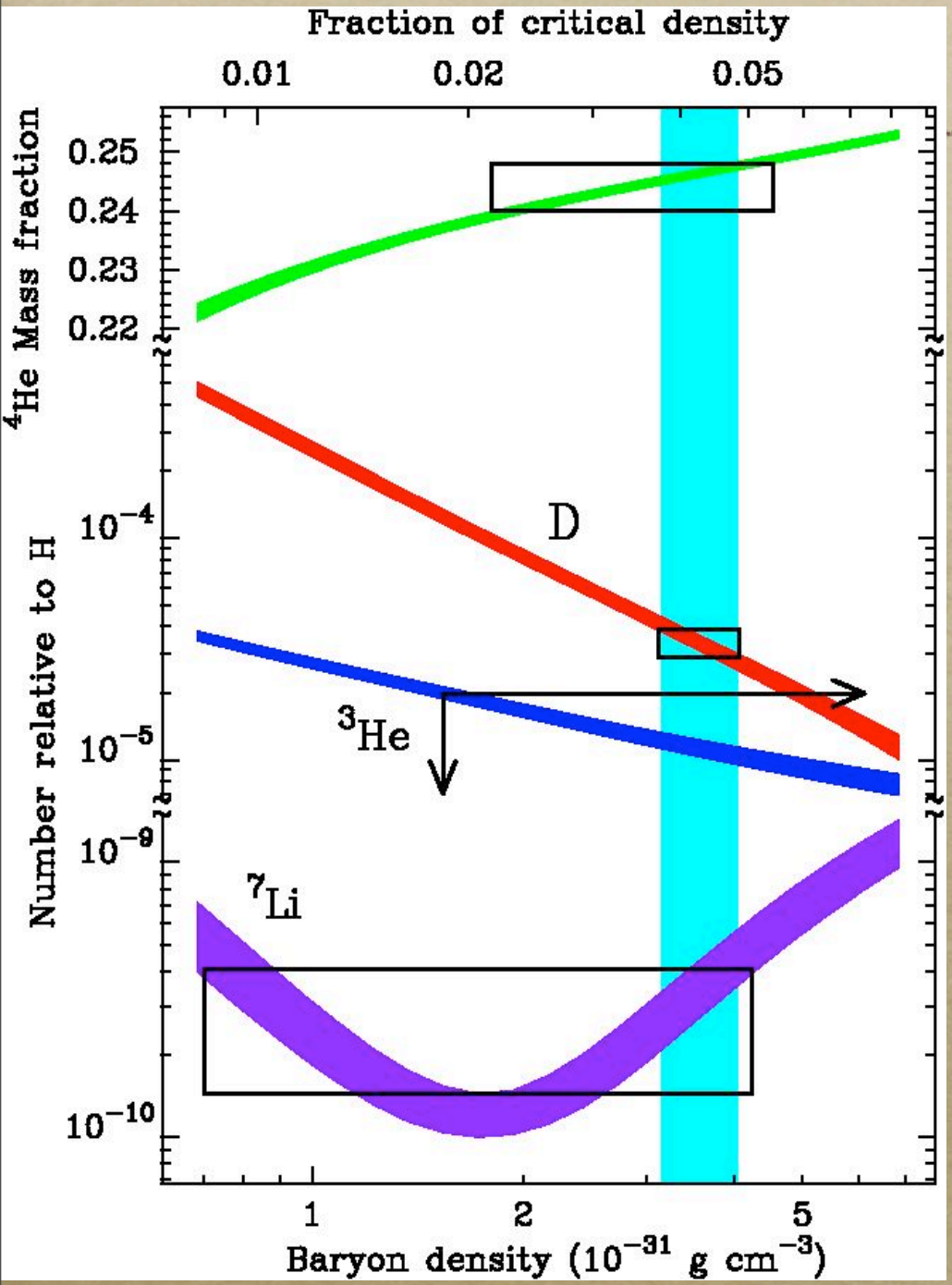
- *the hidden baryons problem*
- *intergalactic medium/galaxy co-evolution*

Cosmological Microwave Background



5 years WMAP

Deuterium Primordial Abundance

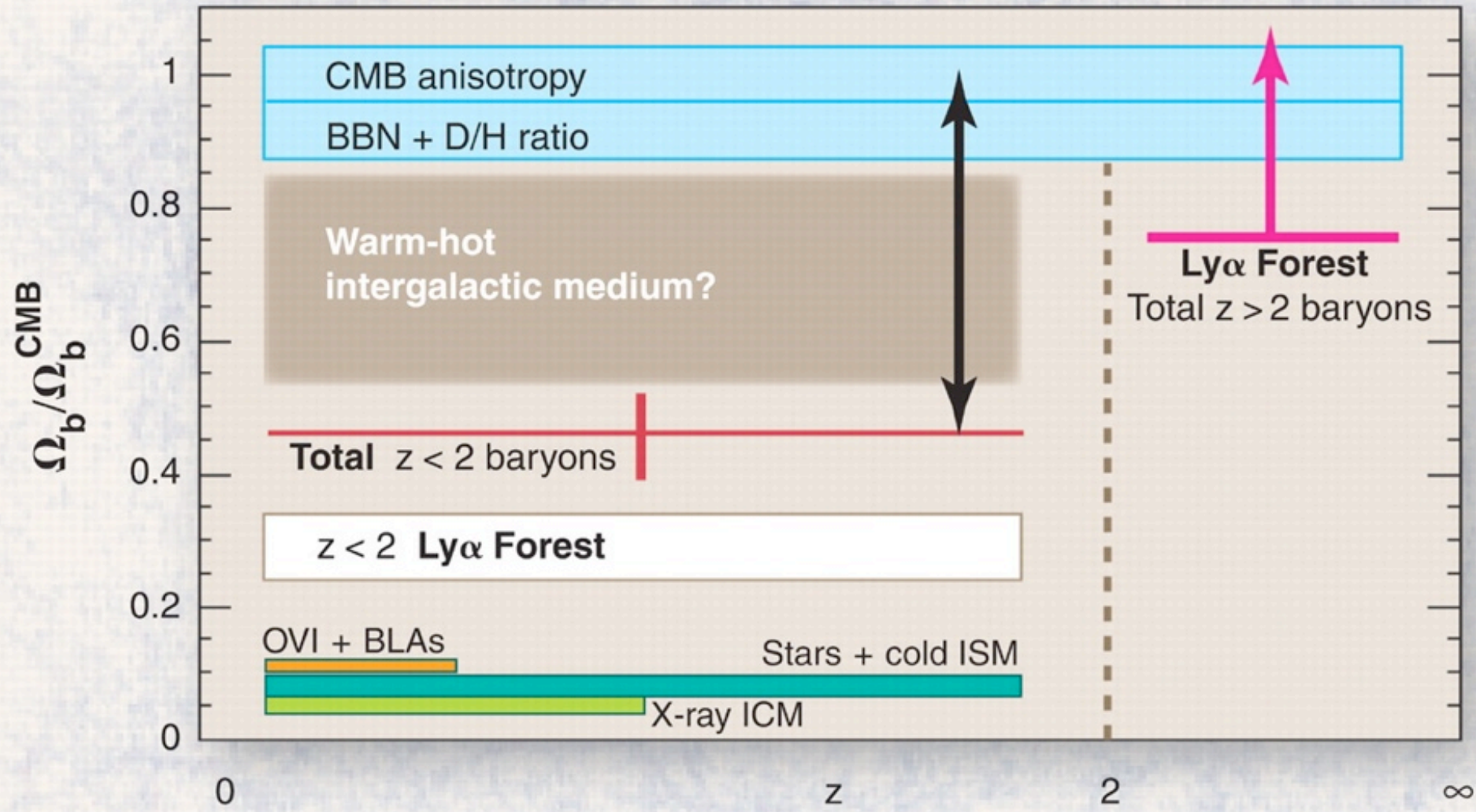


- Constrains on Omega_baryons

- *(Tytler et al. 2000)*

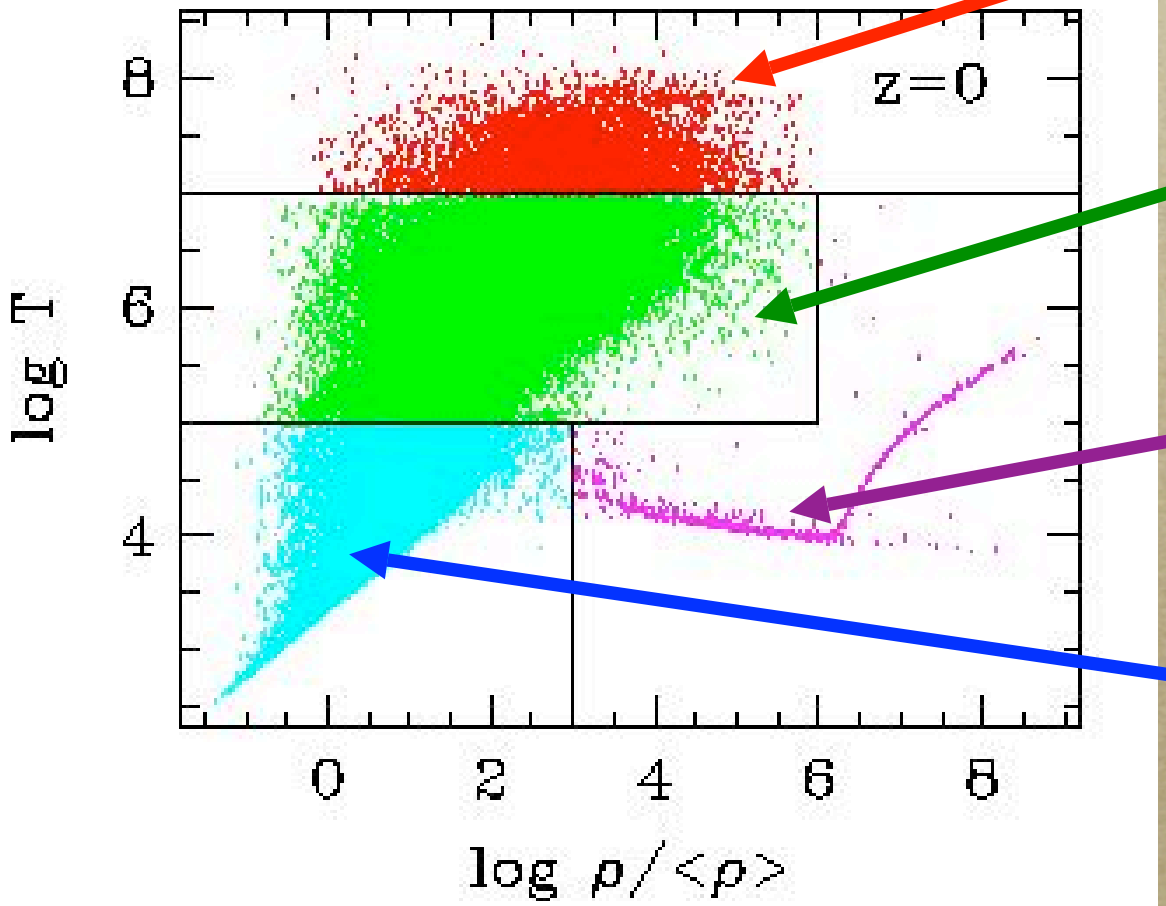
Baryons Census

(Nicastro, Mathur & Elvis 2009, Science)



Phase Diagramme

HOT GAS in CLUSTERS/GROUPS



WHIM (46%)

STARS (7%)

Ly-alpha FOREST

(Davé et al. 2001)

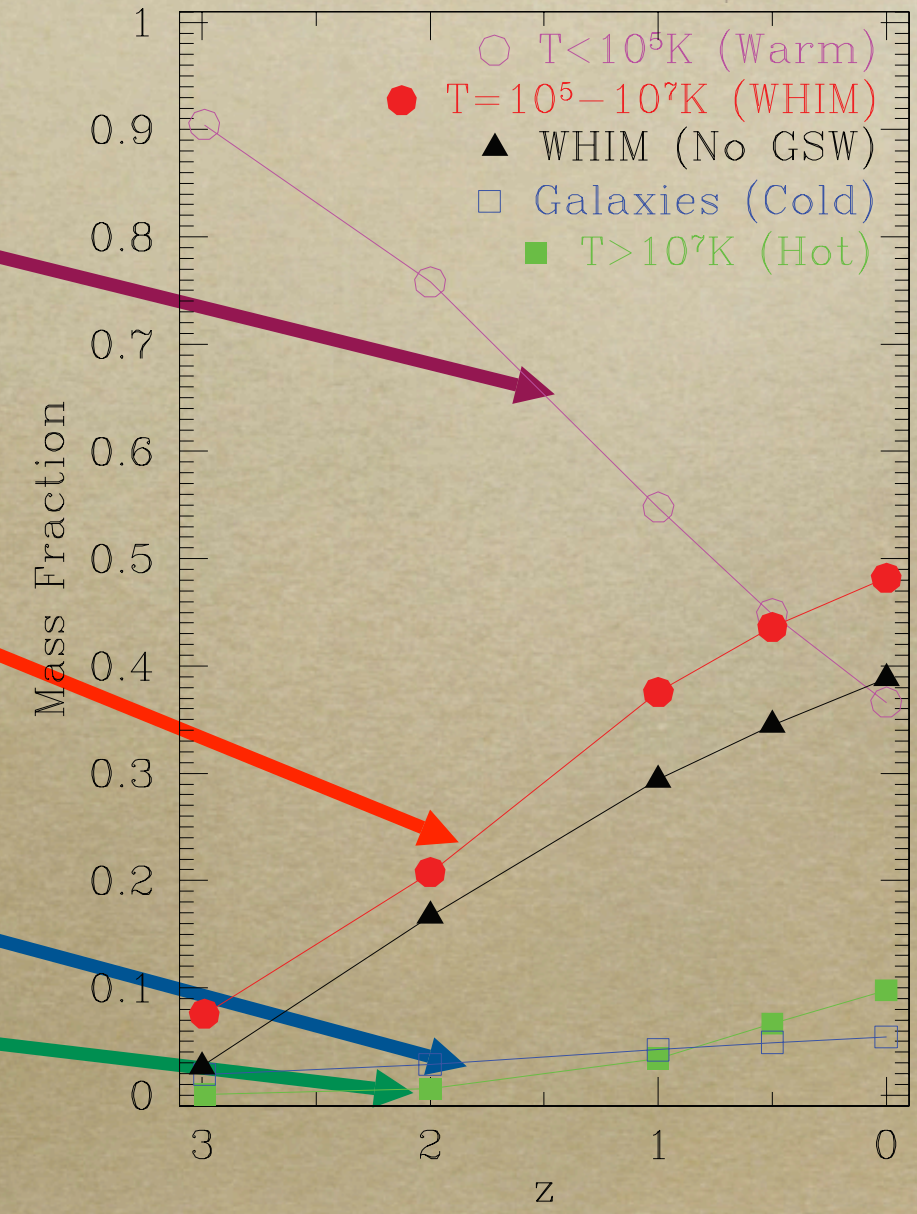
Mass Fraction Evolution

Ly-alpha Forest

WHIM

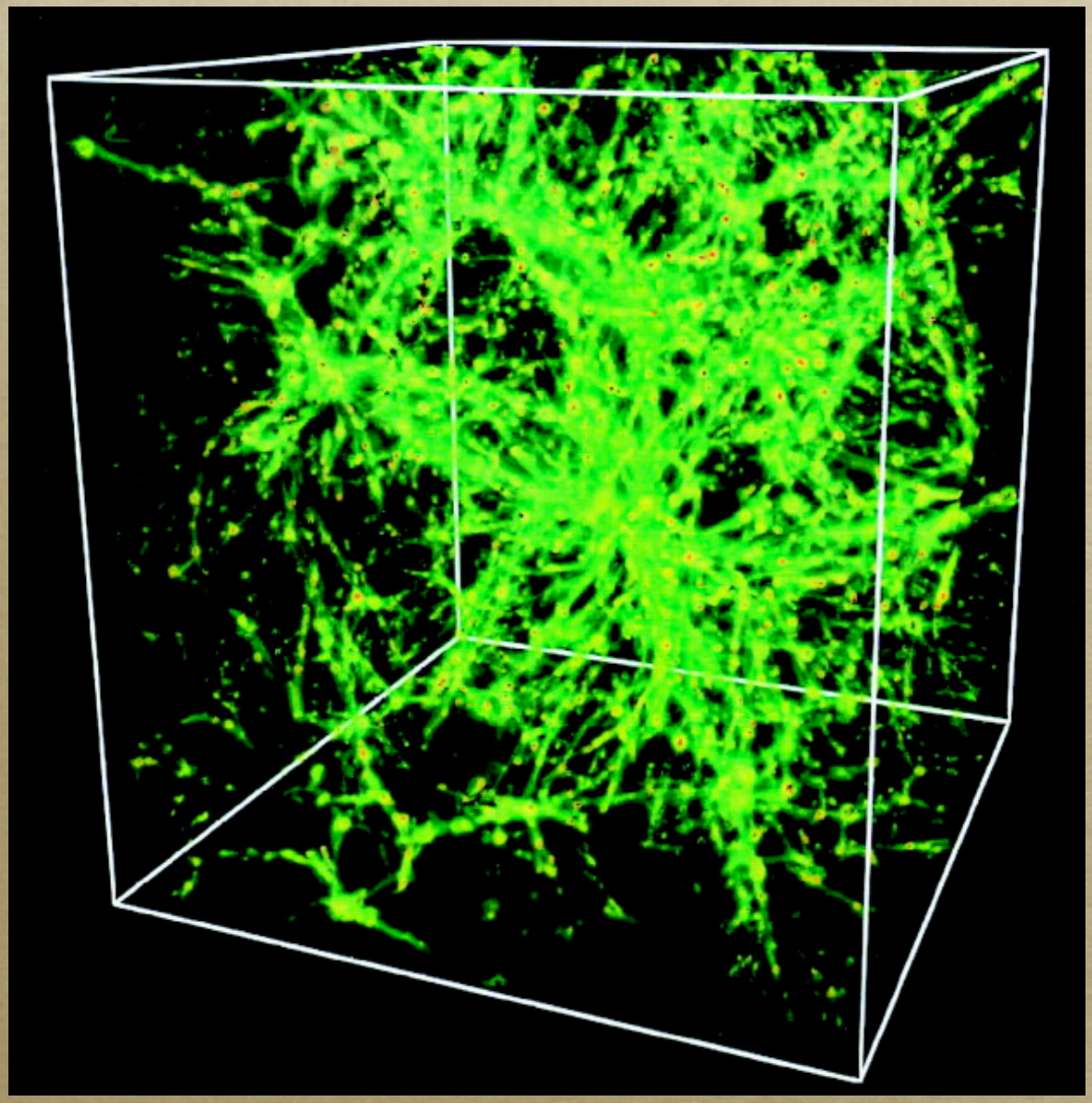
STARS &
GALAXIES

Hot Gas in
Clusters and Groups



(Cen & Ostriker 2006)

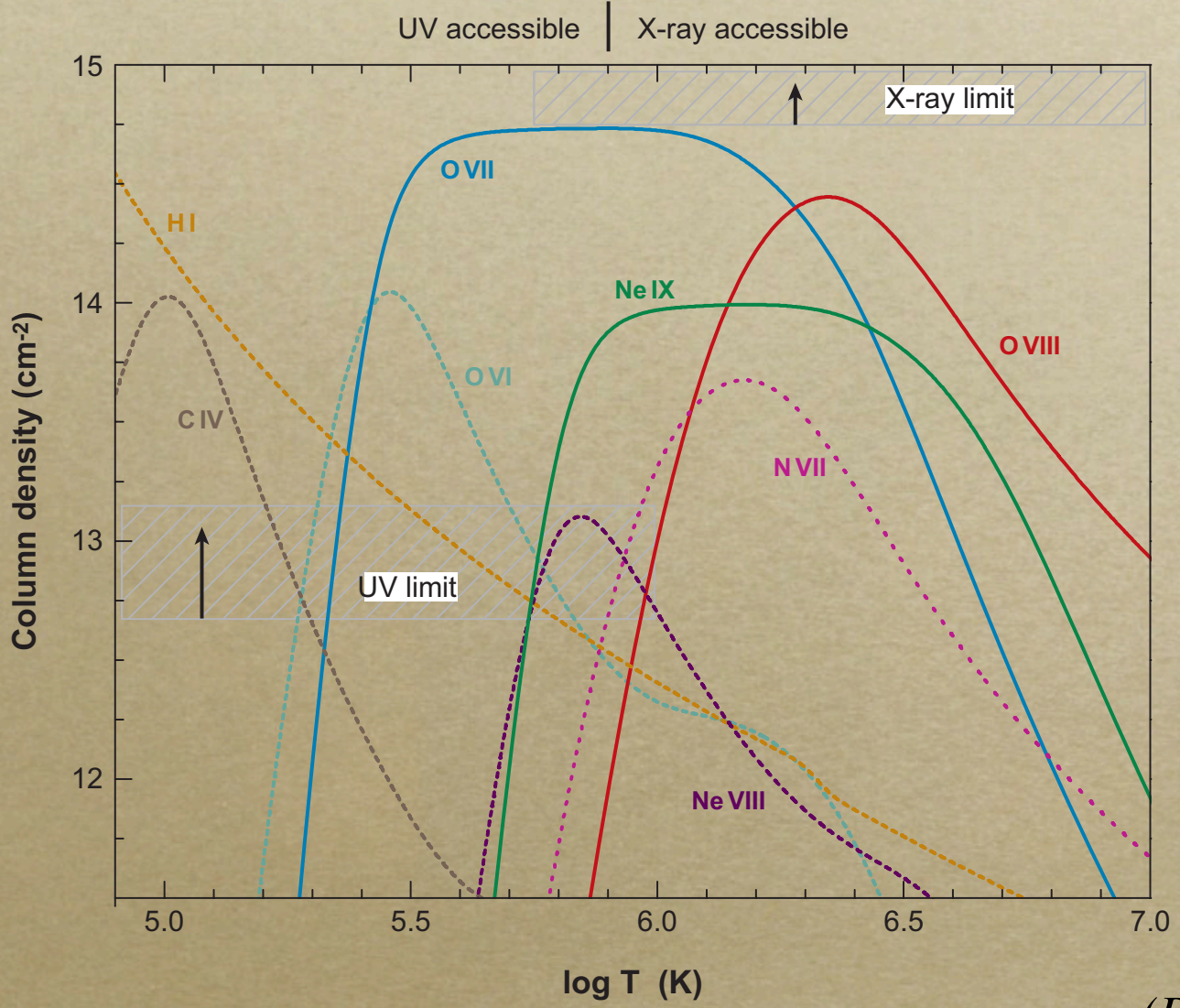
Warm-Hot Intergalactic Medium



- WHIM: gas with $10^5 < T < 10^7$ K
- multiphase ISM, stellar formation, feedback, galactic winds
  ⇒ to reproduce the history of star formation

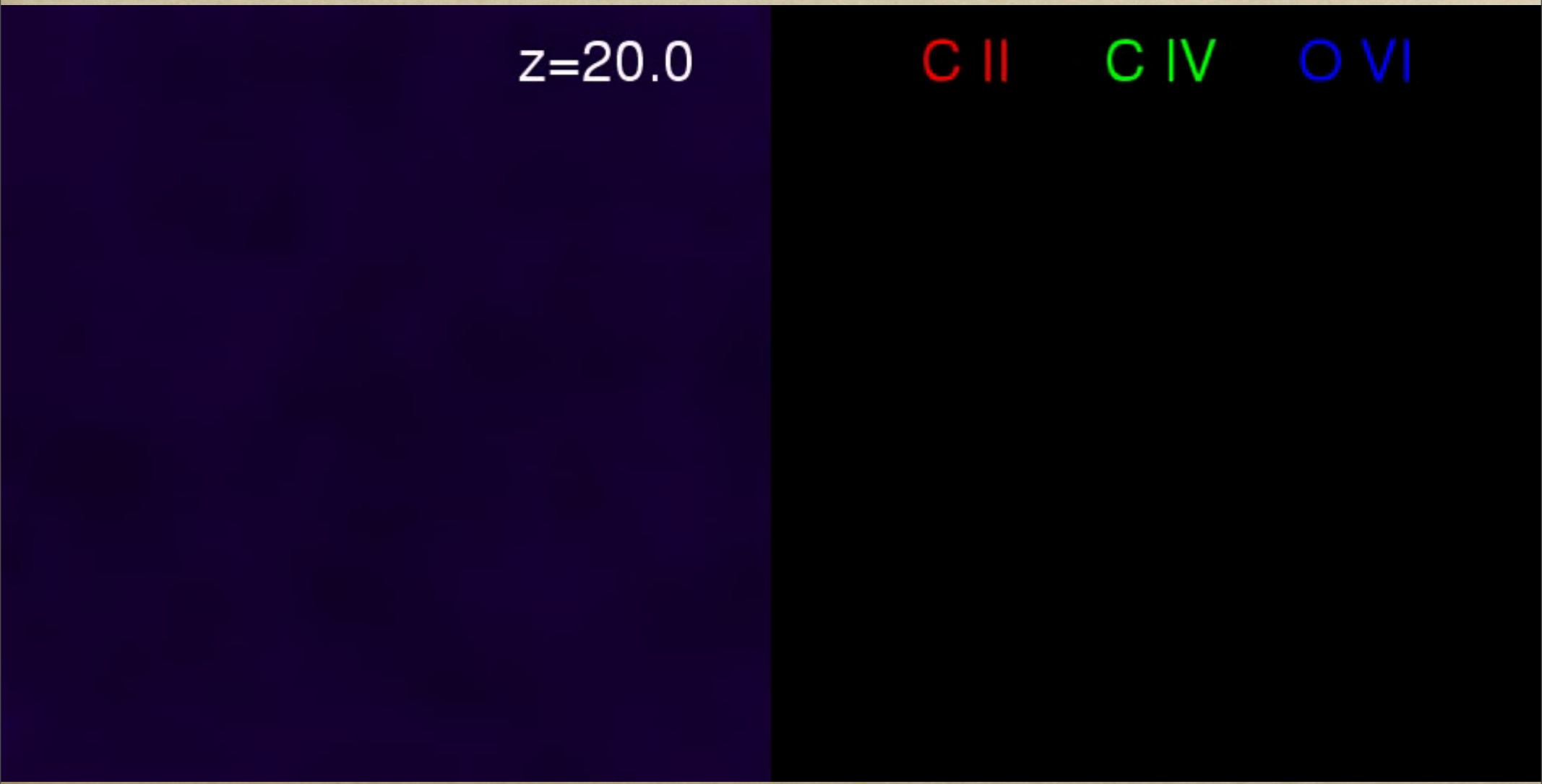
50Mpc/h ΛCDM simulation, with hydro code.
(Cen & Ostriker 1999)

WHIM Tracers



(Bregman 2007, AARA)

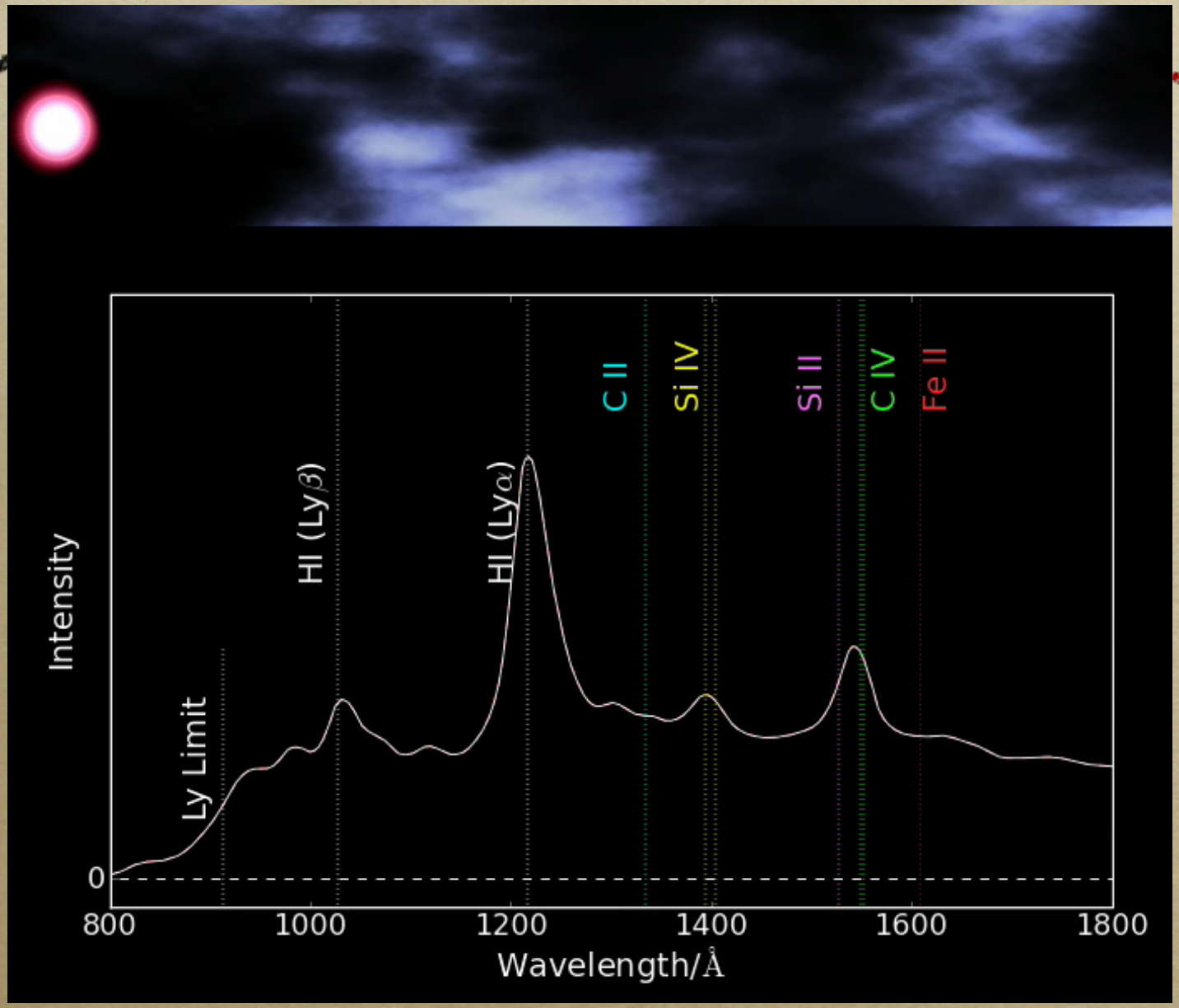
Simulating the IGM



32 Mpc/h box
17,000,000 gas particles

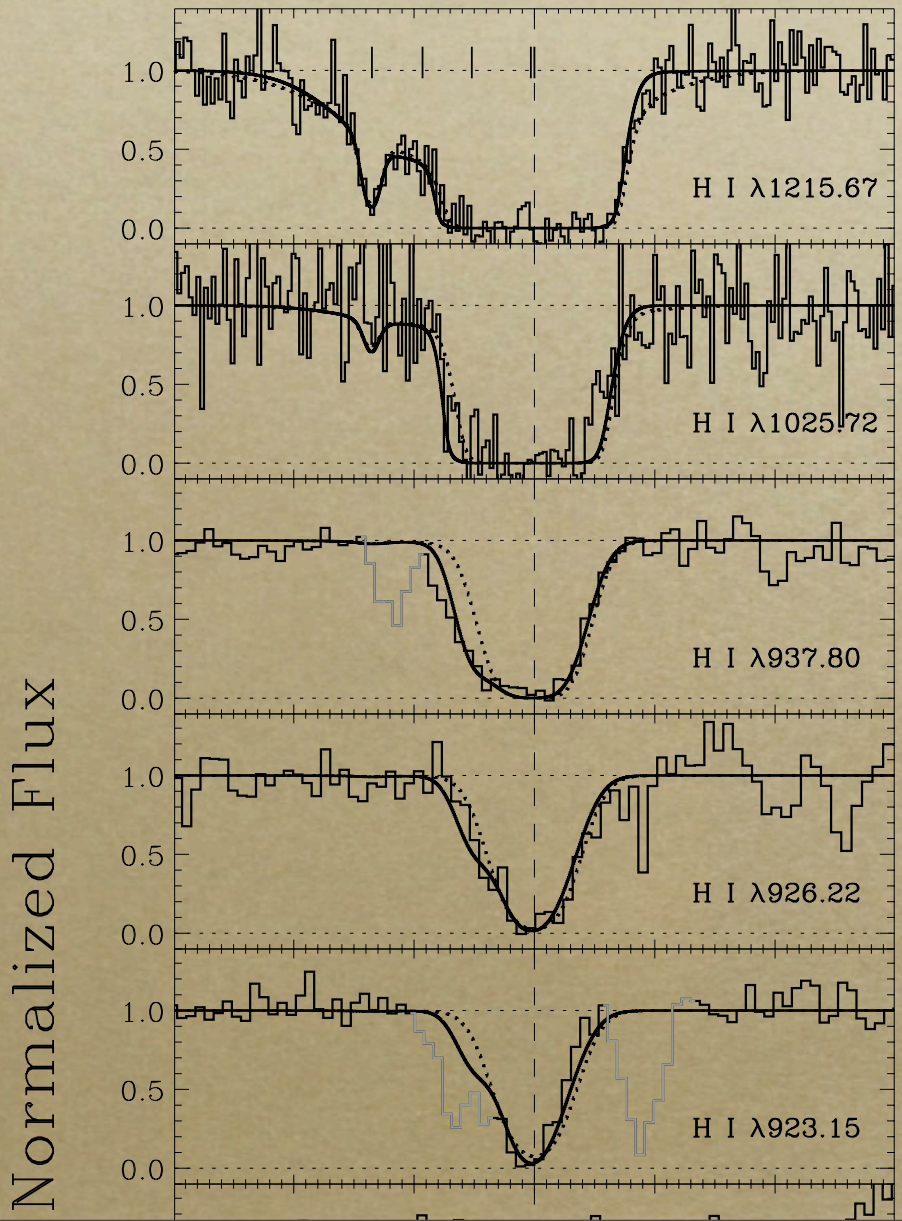
(Oppenheimer, Dave & Finlator 2009)

Observation of the IGM



- *Lyman-alpha Forest*

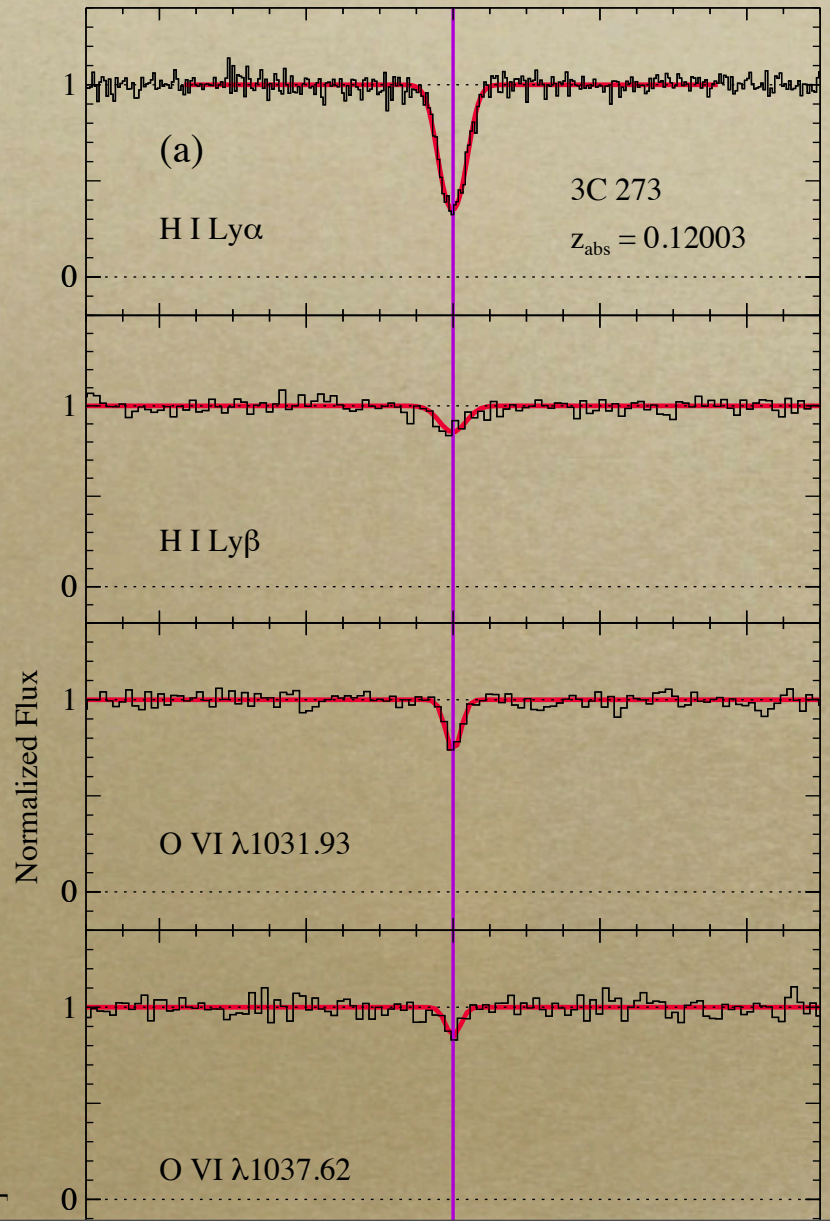
Detected in absorption in Ultra-Violet



- *Absorption in the spectrum of a background source*
- *Broad Lyman-alpha Absorbers (BLA)*

(Lehner et al. 2007)

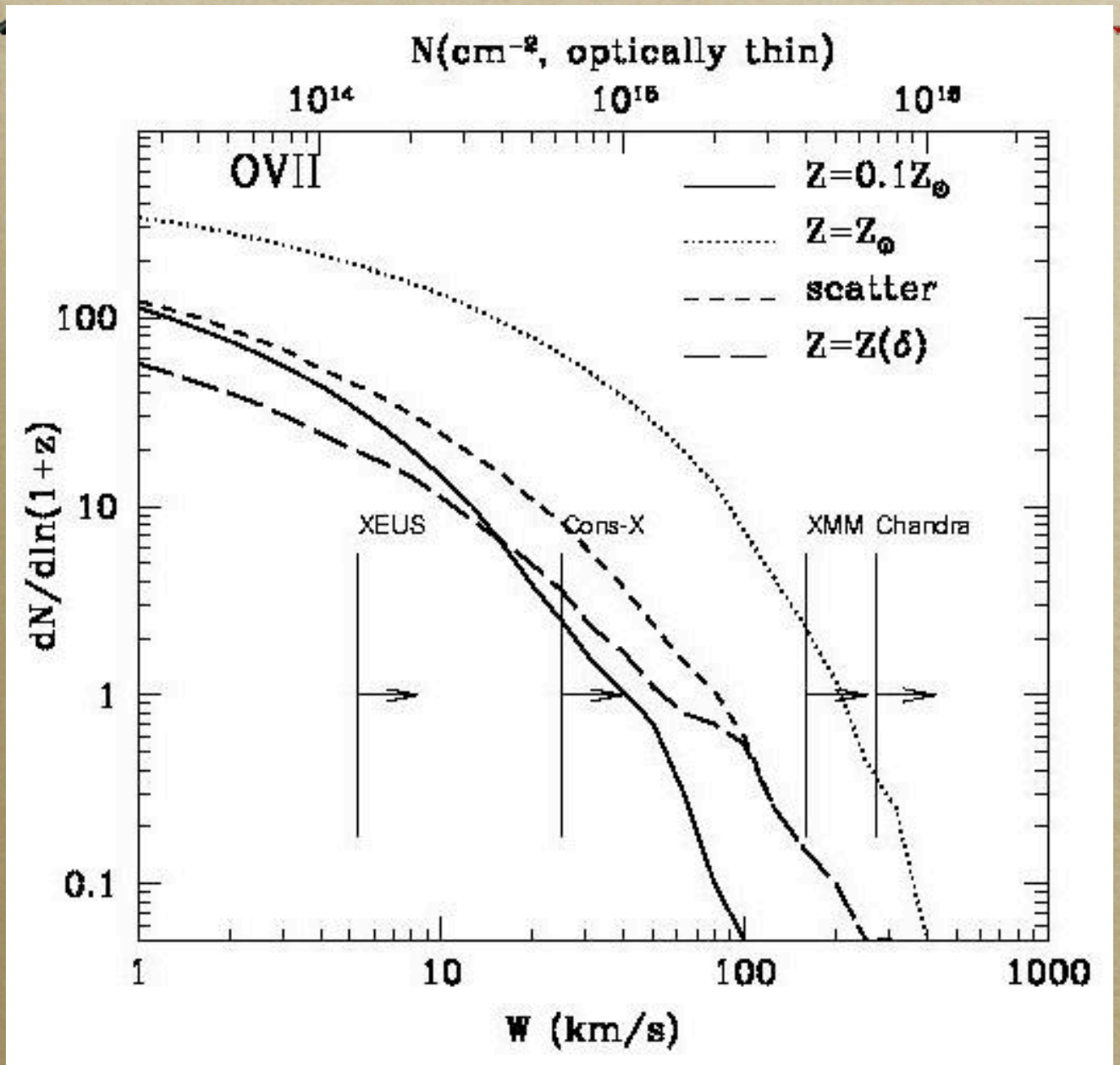
UV Absorption



- *OVI, OVII abs, broad Ly-alpha (UV abs)*

(Tripp et al. 2007)

X-ray Absorption



- *OVII, OVIII :*

$10^6 < T < 10^7$ K

- *pbl with foregrounds*

BINGO! Project

(Agence Nationale de la Recherche)

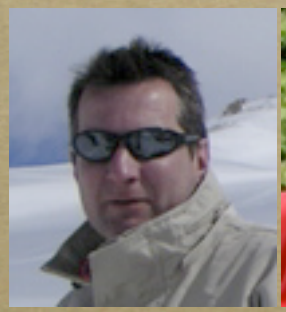
- *Marseille (Deharveng, Milliard, Tresse, Vibert, Conseil, Frank, Popping, Zafar, Peroux)*



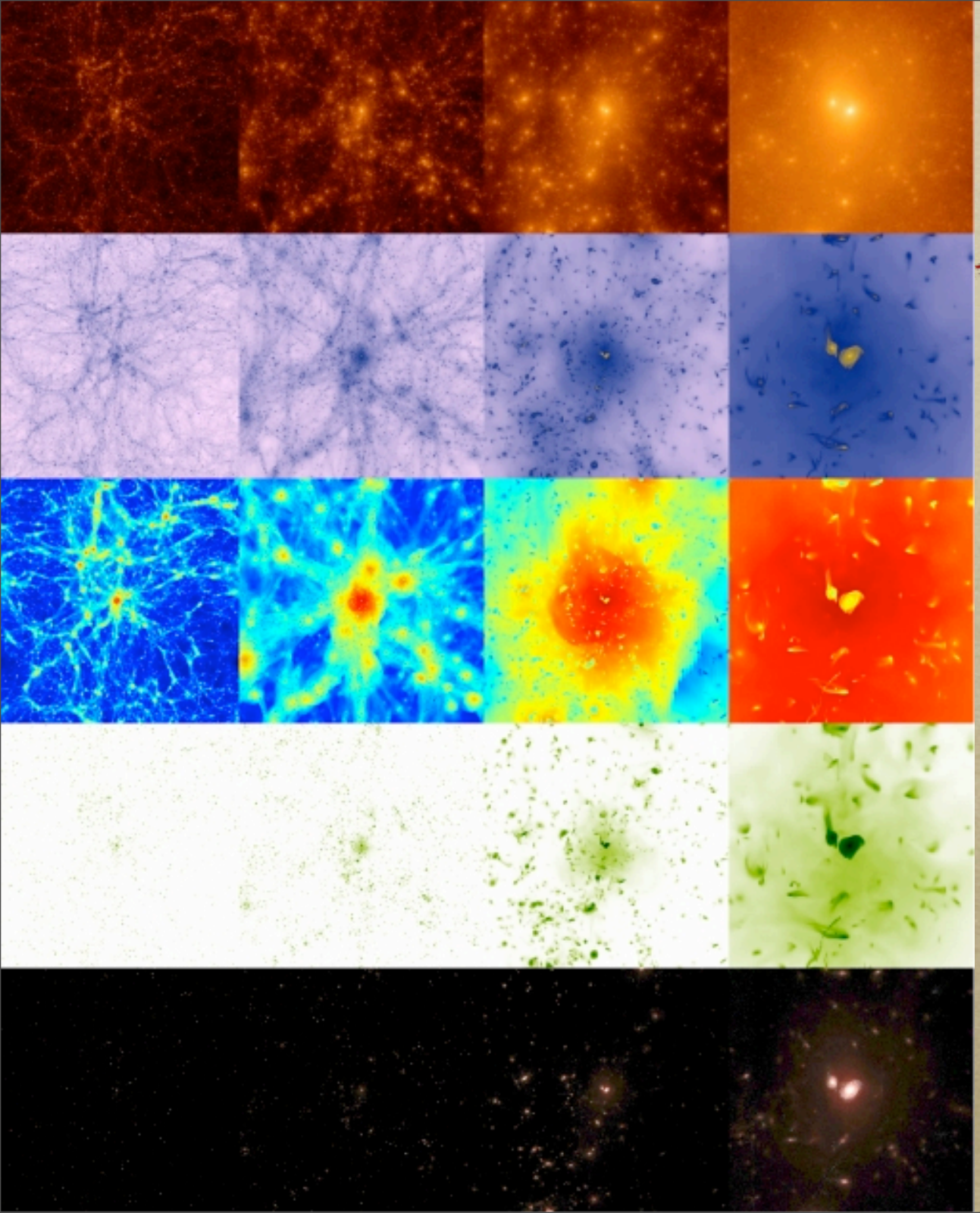





- *Paris (Teyssier, Rasera, Charlot)*



- *Lyon (Blaizot, Courty)*

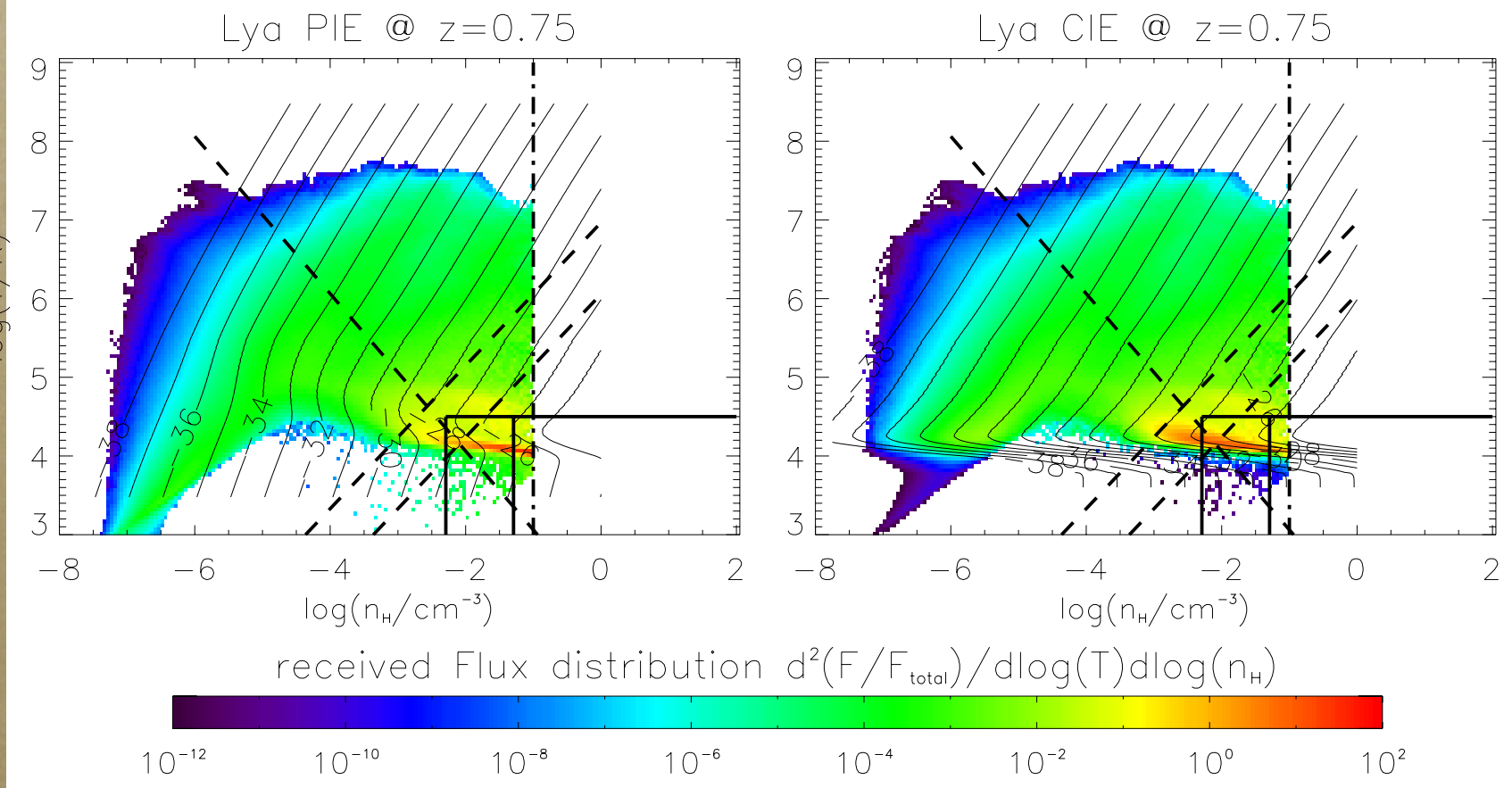
Mare Nostrum Simulation

- dark matter density
- gas density
- gas temperature
- star colors

=> study possibility to look for signture of WHIM in emission
=> approach based on simulation + observations

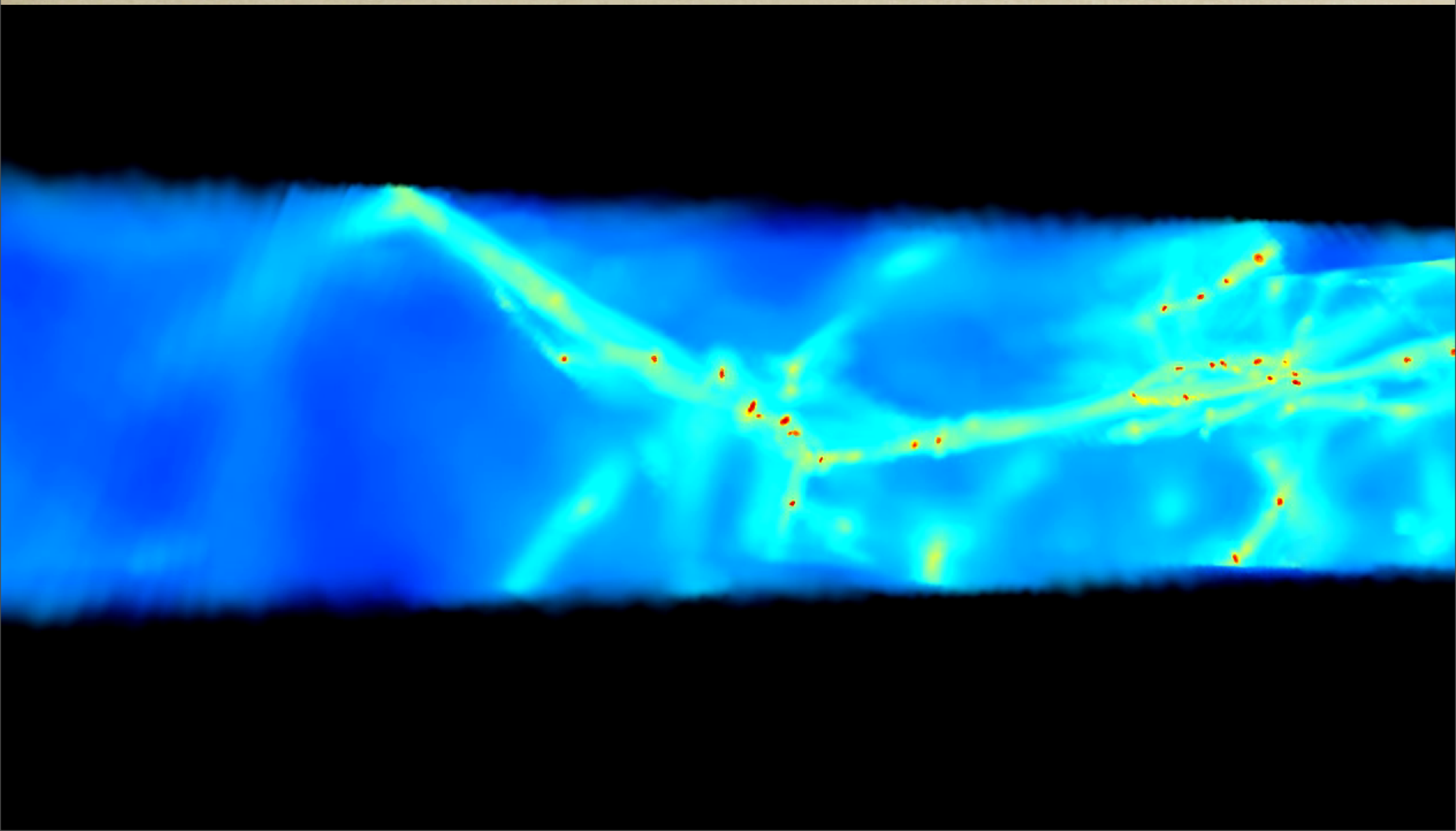
(Rasera & Teyssier)

Phase Diagramme



Frank et al. (2011)

Lyman-alpha Emission



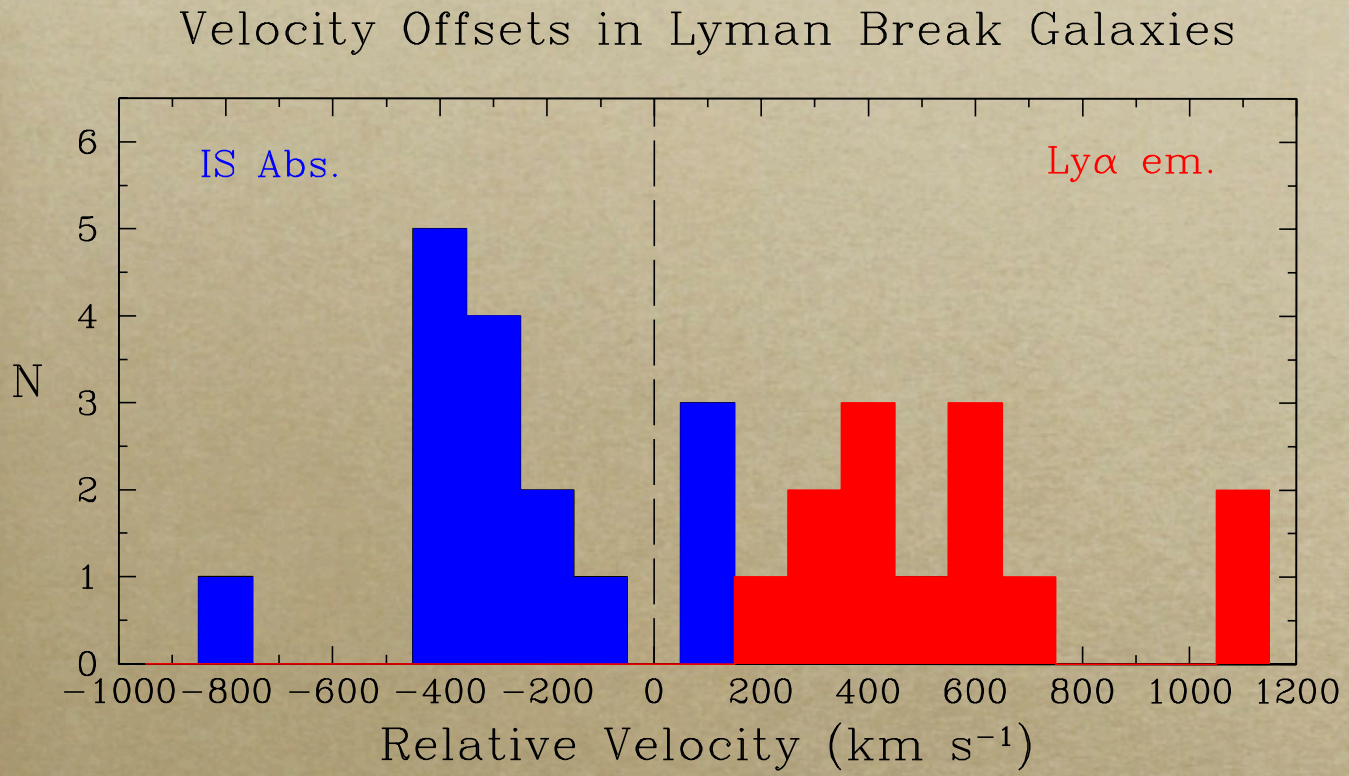
FIREBall Instrument

- *balloon-born*
- *2000 Ang window*
- *1st flight July 2007*
- *science flight May 2009*
  => upper limits
- *next flight 2013-2014*

Overview

- *the hidden baryons problem*
- *intergalactic medium/galaxy co-evolution*

Evidence for Winds



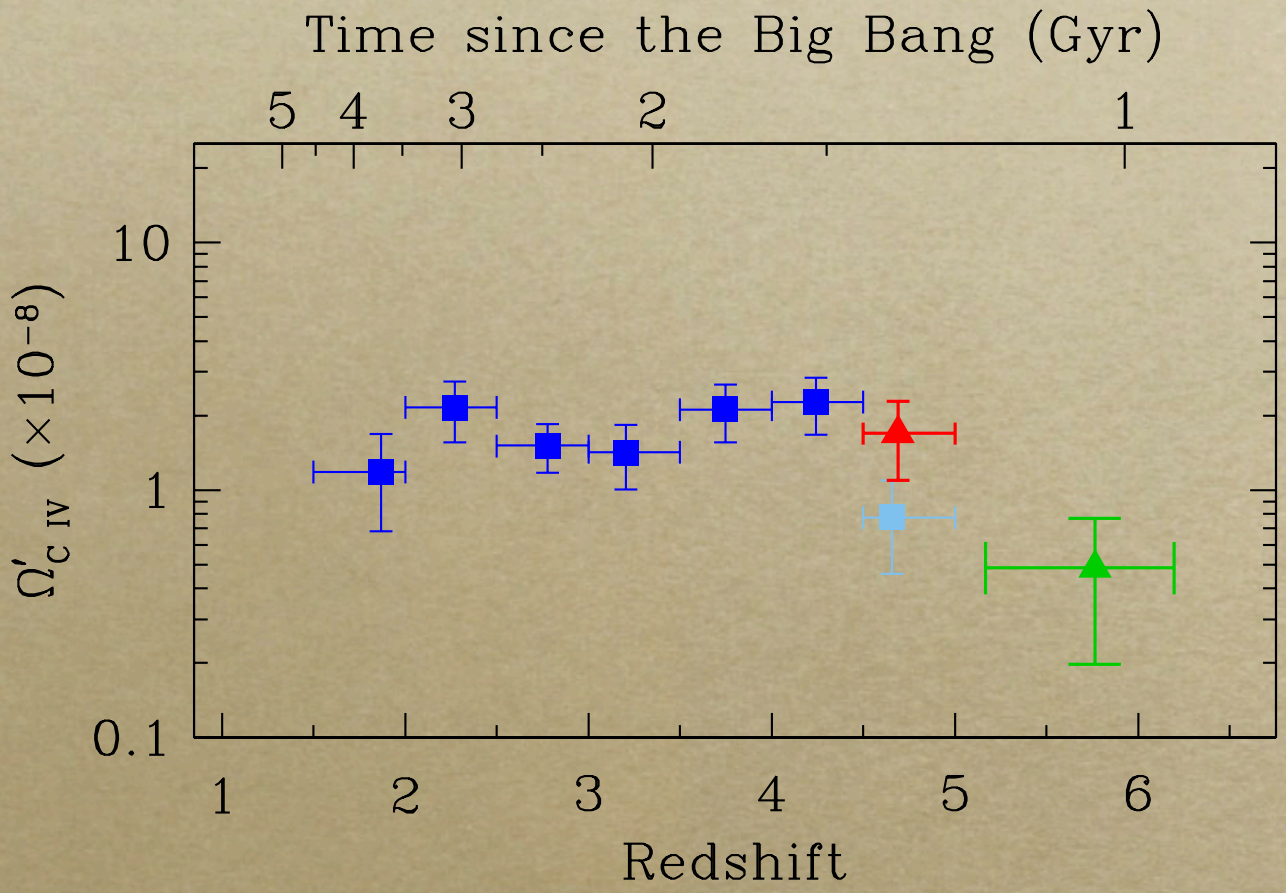
- *outflows*

(Pettini 2003)

Other Observational Evidence for Winds

- *NaID in local ULIRGS (Crystal Martin et al.)*
- *MgII in high-z galaxies*
- *UV-bright galaxies (Heckman et al.)*

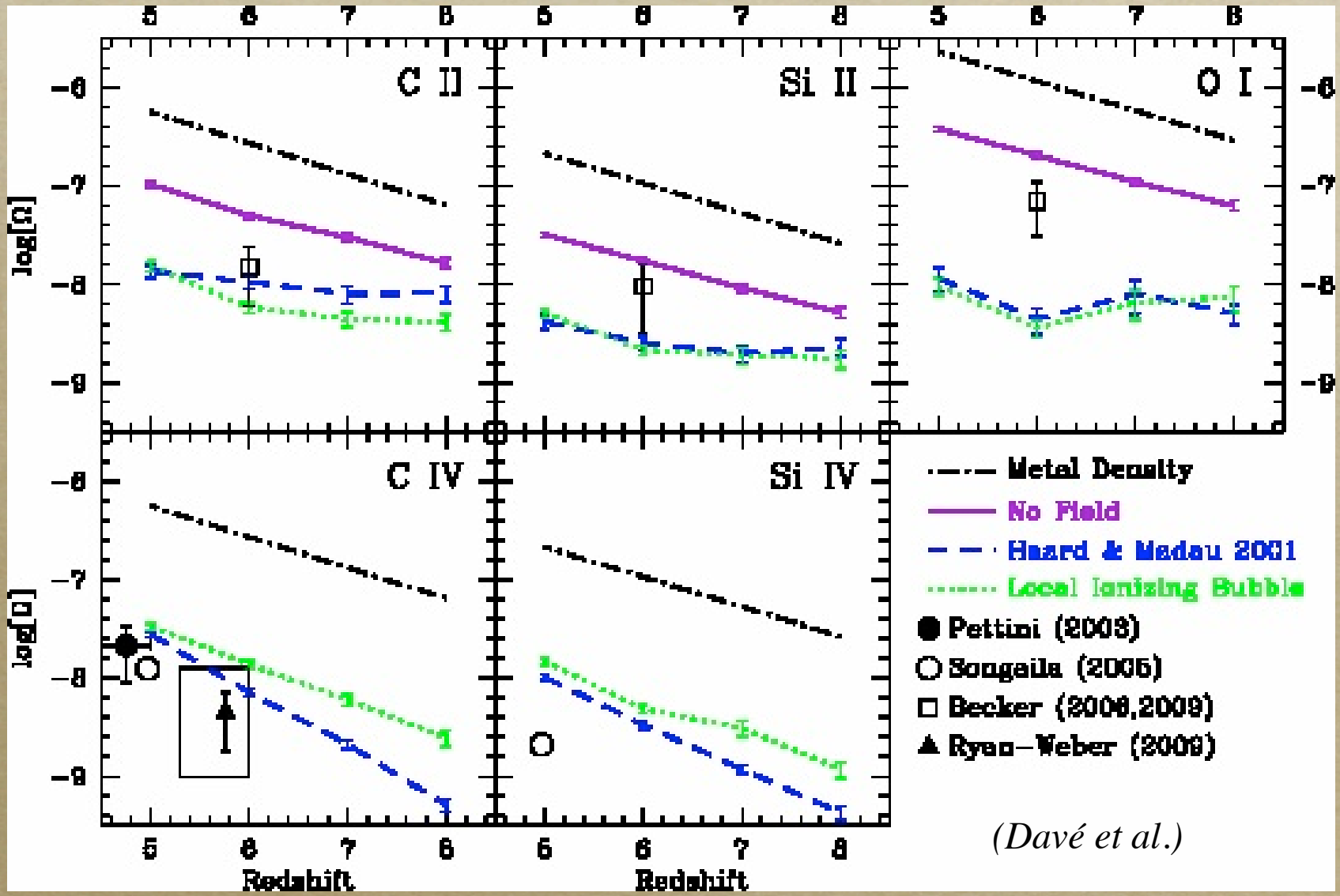
Metal Pollution



- *Carbon IV evolution in the IGM*

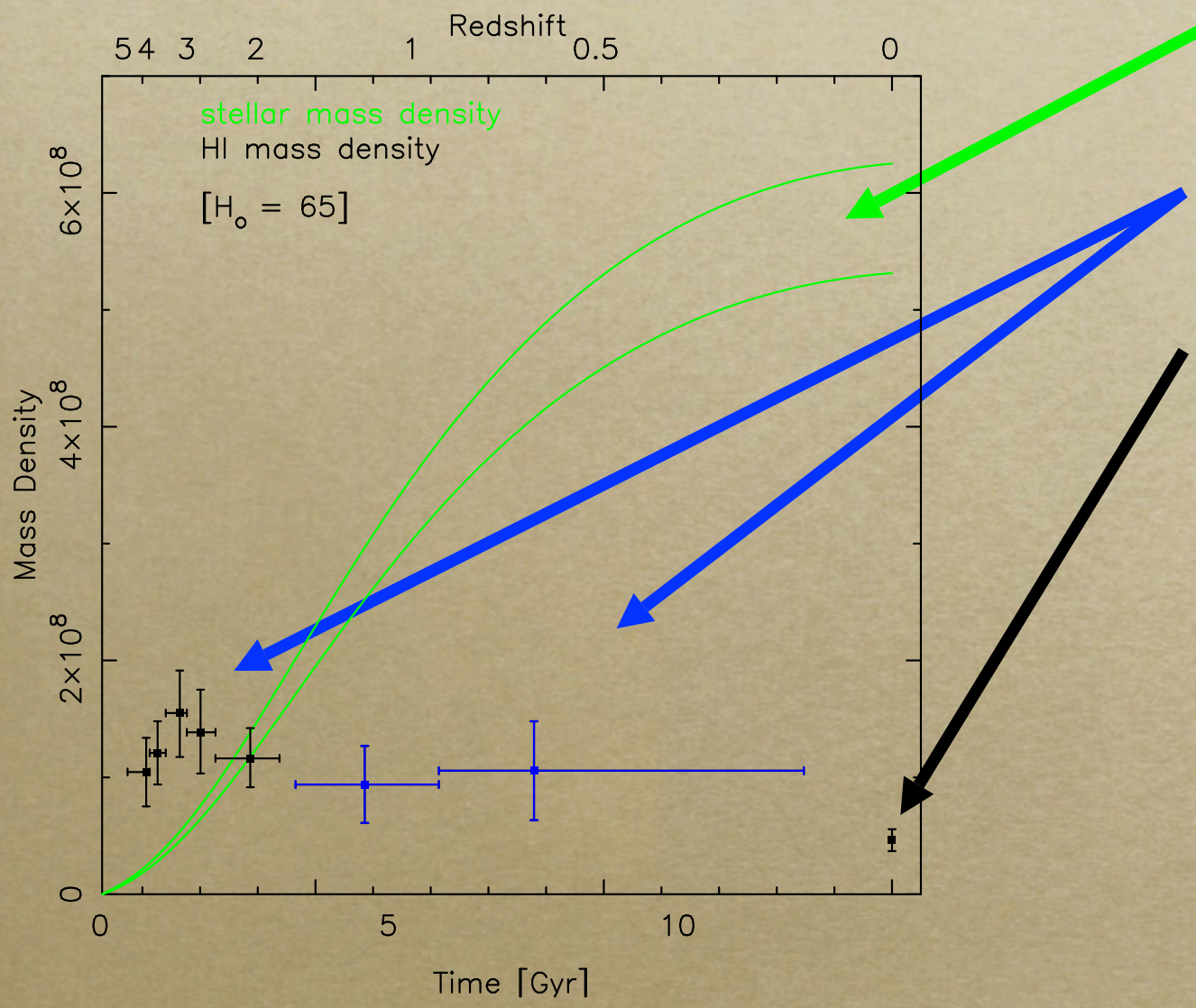
(Ryan-Weber, Pettini, Madau & Zych 2009)

Simulations of Omega_CIV



(Davé et al.)

Evidence for Accretion



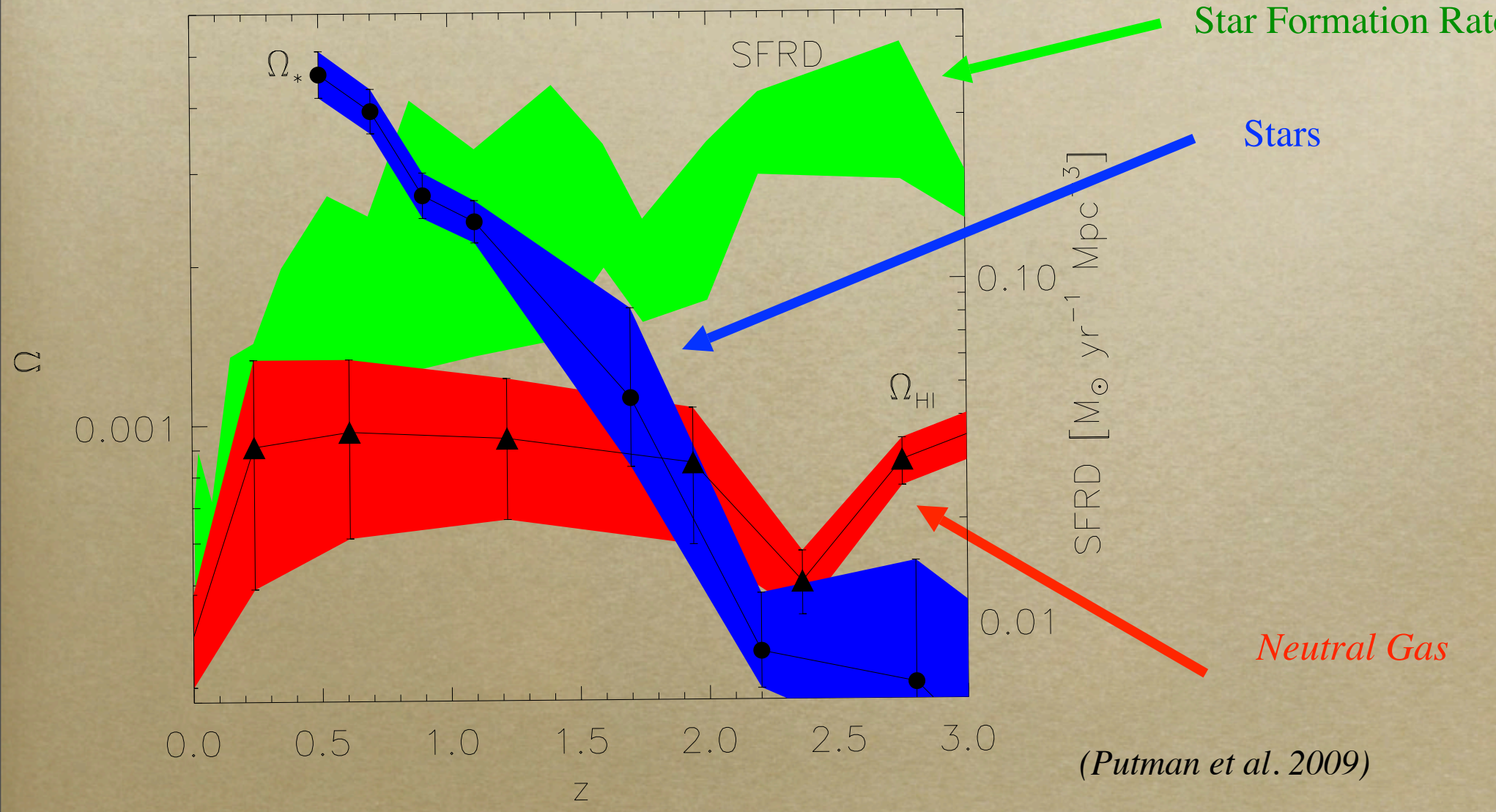
STARS

GAS HI

LOCAL GALAXIES

(Péroux et al. 2005)

Evidence for Accretion



(Putman et al. 2009)

Simulations of DLAs

Table 1. Selected previous simulations of DLAs.

Reference(s)	Type	SF	Ionization/RT	Max Vol[1]	Gas res[2]
Katz et al. (1996b)	SPH	None	Plane correction[3]	$(22\,\mathrm{Mpc})^3$	$10^{8.2}\,M_\odot$
Gardner et al. (1997a)	SPH	None	Plane correction[3]	$(22\,\mathrm{Mpc})^3$	$10^{8.2}\,M_\odot$
Gardner et al. (1997b)					
Haehnelt et al. (1998)	SPH	None	Den. cut[4]	N/A[5]	$10^{6.7}\,M_\odot$
Gardner et al. (2001)	SPH	Yes, weak FB[6]	Plane correction[3]	$(17\,\mathrm{Mpc})^3$	$10^{8.2}\,M_\odot$
Cen et al. (2003)	Eulerian	Yes, with FB[6]	Hybrid[7]	$(36\,\mathrm{Mpc})^3$	11 kpc
Nagamine et al. (2004a)	SPH	Multiphase/GW[8]	Eq. thin/MP[8]	$(34\,\mathrm{Mpc})^3$	$10^{4.6}\,M_\odot$
Nagamine et al. (2004b)					
R06	Adpt Eulerian[9]	None	Non-eq. live RT/post-processor[10]	$(8\,\mathrm{Mpc})^3$	0.1 kpc
Nagamine et al. (2007)	SPH	Multiphase/GW[8]	Eq. thin/MP[8]	$(14\,\mathrm{Mpc})^3$	$10^{5.0}\,M_\odot$
R08	Adpt Eulerian[9]	Basic	Non-eq. thin/post-processor[10]	$(45\,\mathrm{Mpc})^3$	0.09 kpc
This work	SPH	Yes, with FB[6,11]	Eq. thin/RT post-processor[11]	$(25\,\mathrm{Mpc})^3$	$10^{4.0}\,M_\odot$

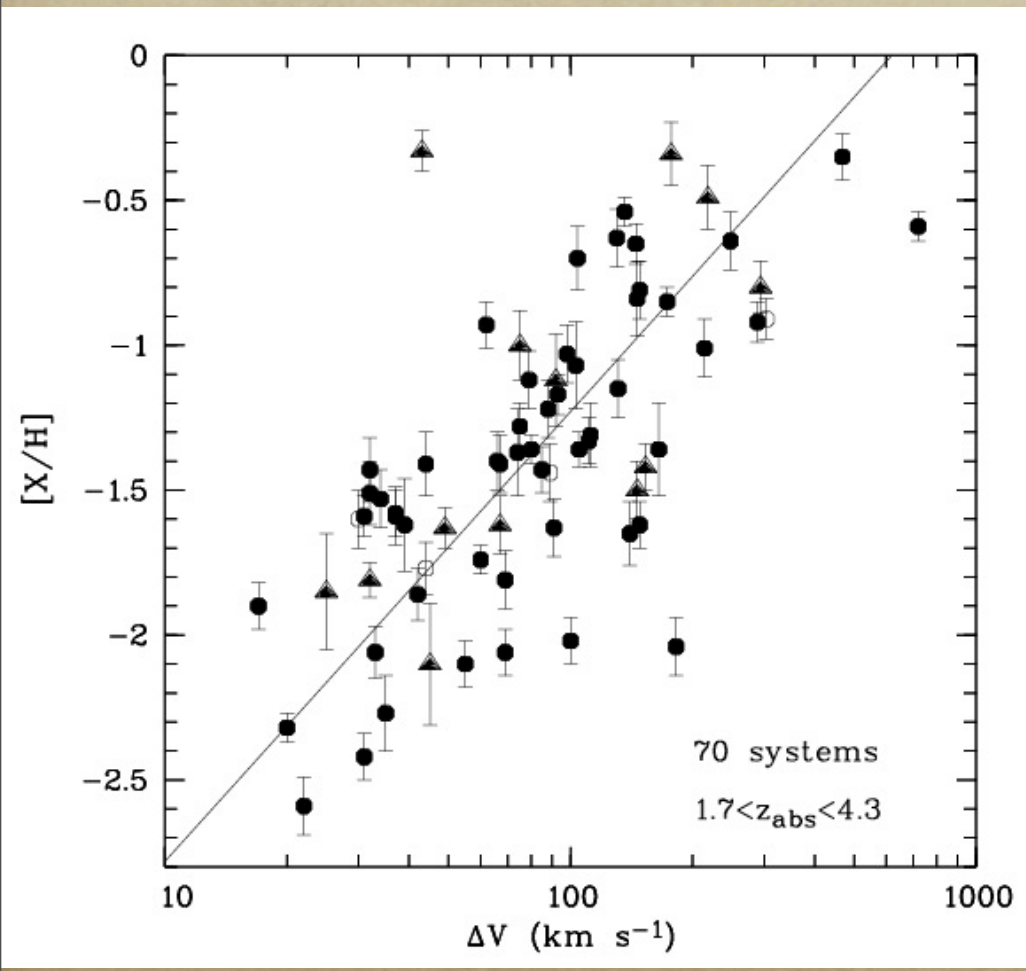
[1]The largest volume simulated for the study, in comoving units.
[2]The best gas resolution achieved in the study, which may not have been achieved in the largest volume. For SPH (Lagrangian) simulations, we give the smallest particle mass; for Eulerian simulations, we give the finest grid resolution (in physical units at $z = 3$).
[3]UV background in optically thin limit; sightlines post-processed using plane-parallel radiative transfer and ionization equilibrium.
[4]UVB optically thin, but in post-processing all gas particles assumed fully neutral for number densities $n > 10^{-2}\,\mathrm{cm}^{-3}$.

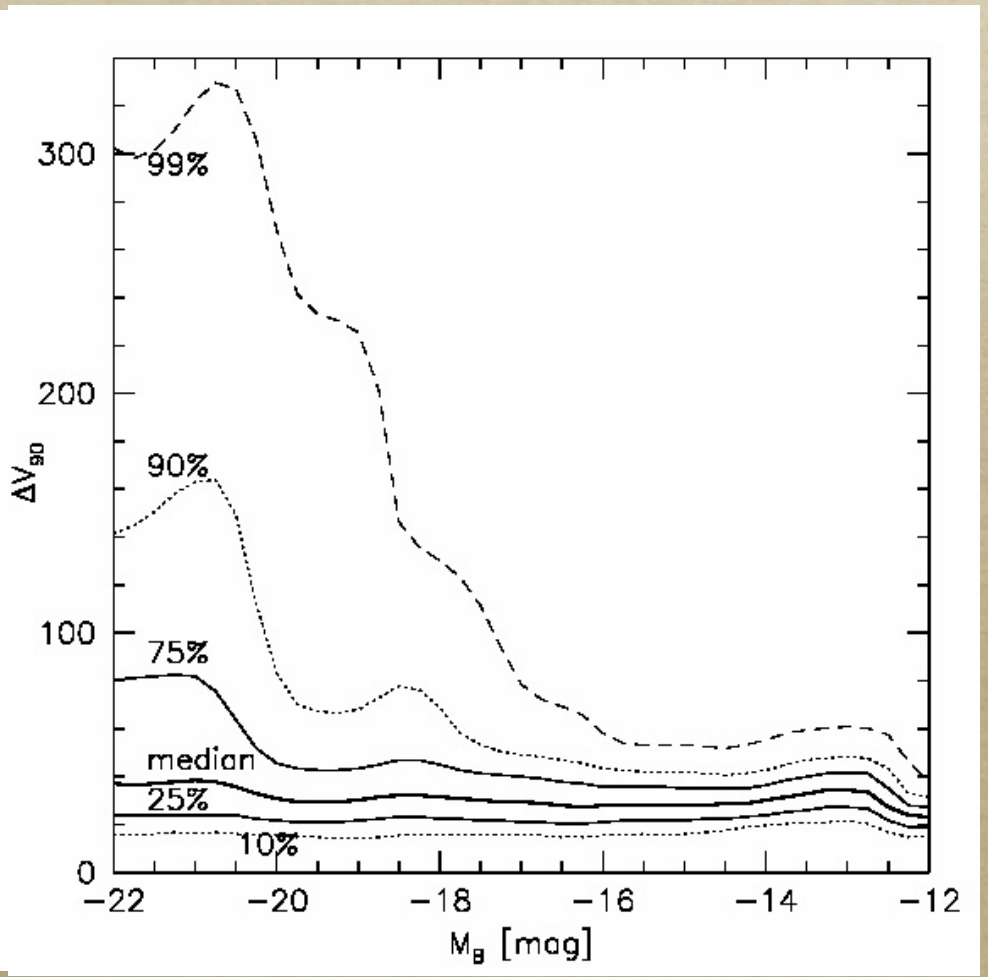
Simulation of Omega_HI

- Nagamine 04, Tescari 09: mass reprocessing
- Pontzen 08: only z~3
- Hopkins et al., Bauermeister et al., Obrewskov et al.

=> new data coming with BOSS (BigBOSS, ngCFHT)

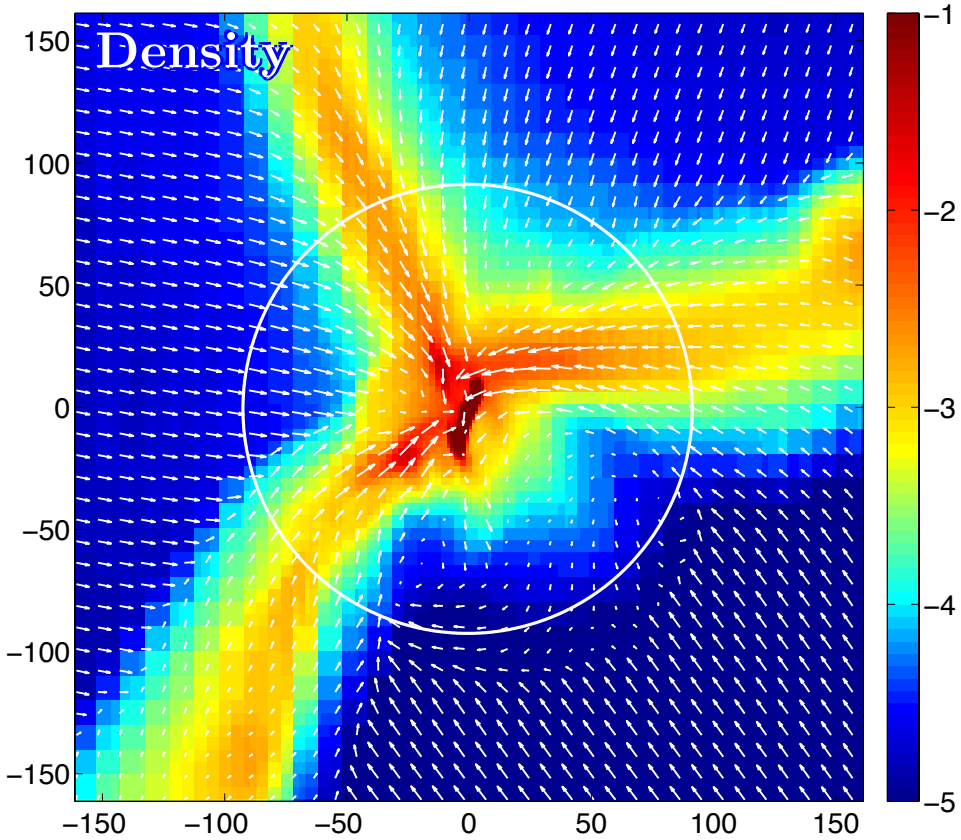
Is Delta_v a good proxy for mass?

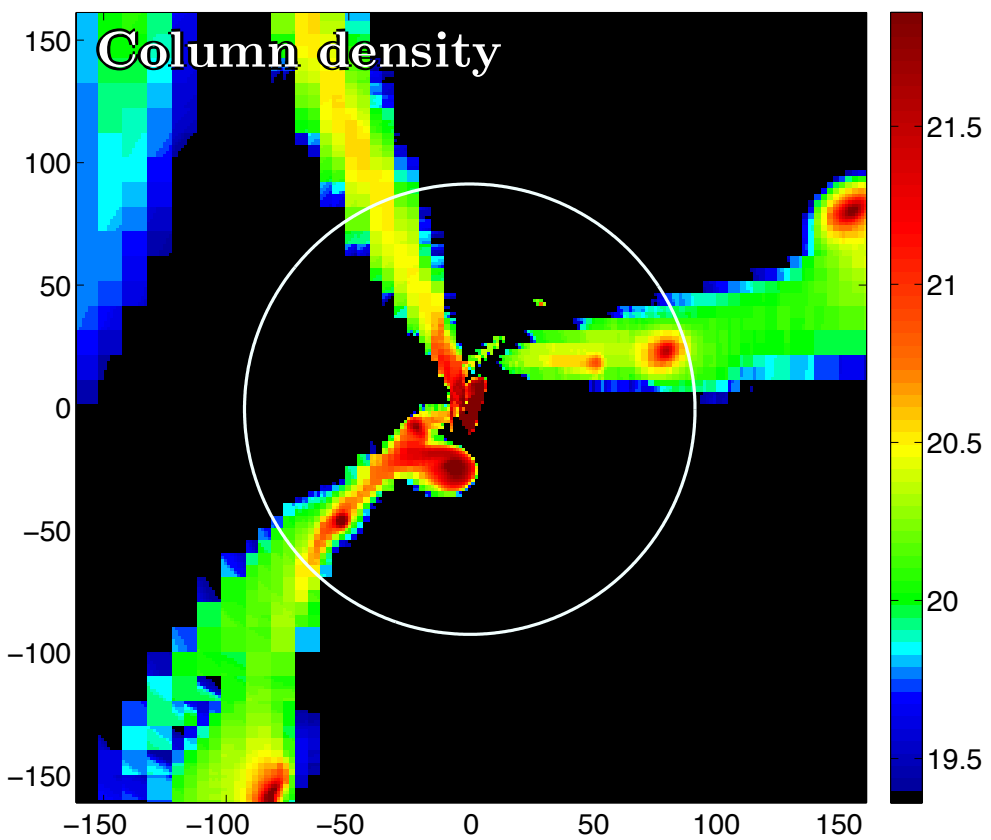




Ledoux et al., Zwaan et al.

Accretion along Filaments

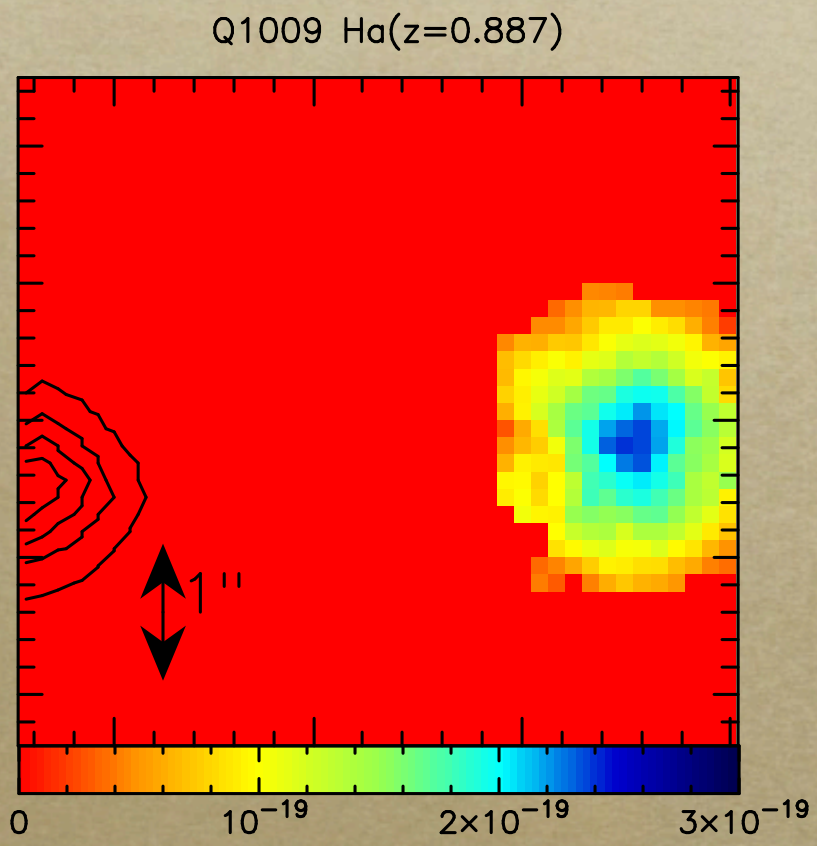




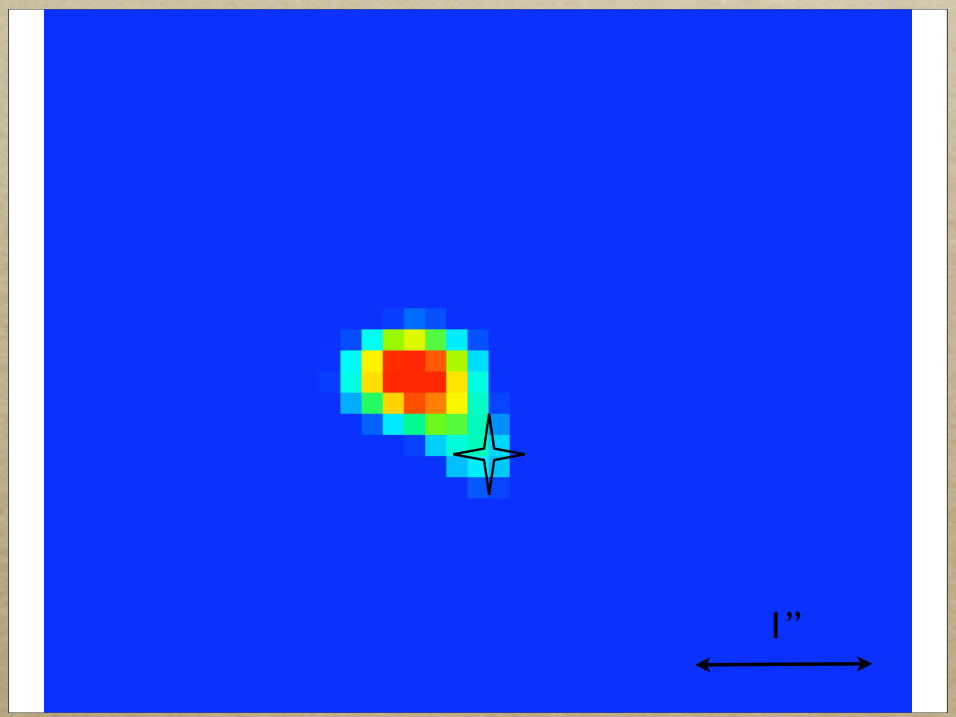
(Dekel et al. 2008)

Connecting Gas & Star Formation

- *Looking in emission for absorbing gas with SINFONI*



z~2



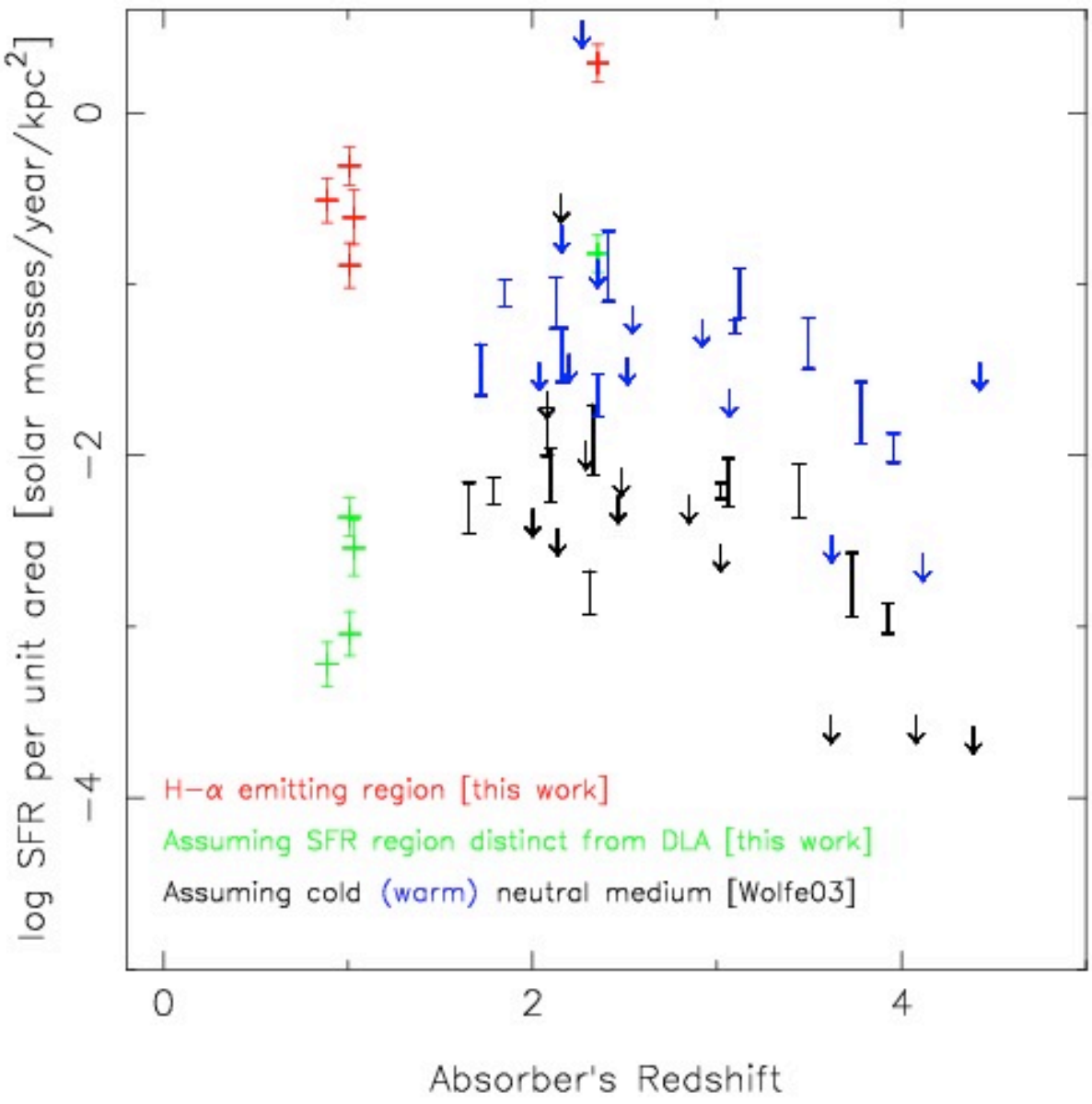
(Peroux, Bouche et al. 2011a, 2011c)

SFR per unit area

- *robust estimates*

*+ 1 non-detection with known CII**

(Peroux, Bouche et al. 2011c)

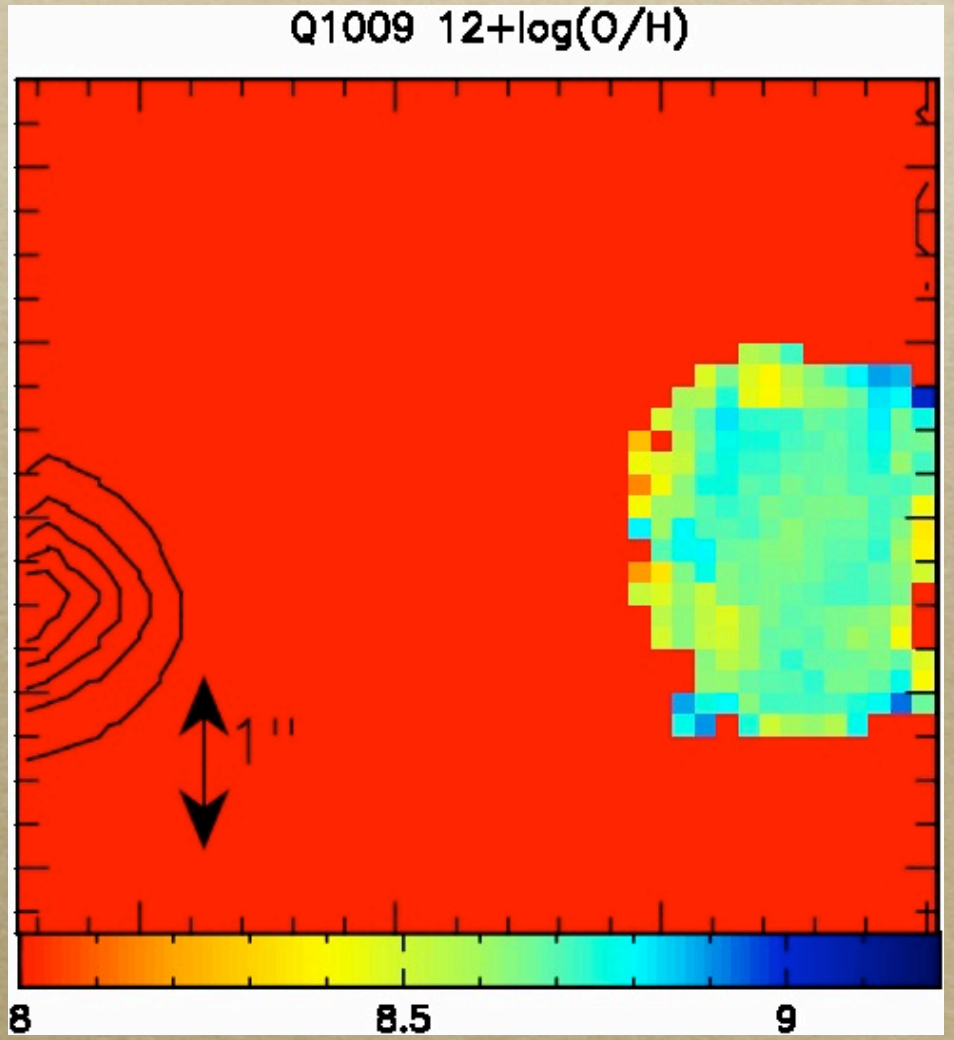


Metallicity Map

- *N2 parameter (Pettini & Pagel 2004)*
- *collapsed [NII]/H-alpha ratio map*
- *metallicity rather uniform*

=> possible signature of accretion

(Cresci et al. 2010, Nature)

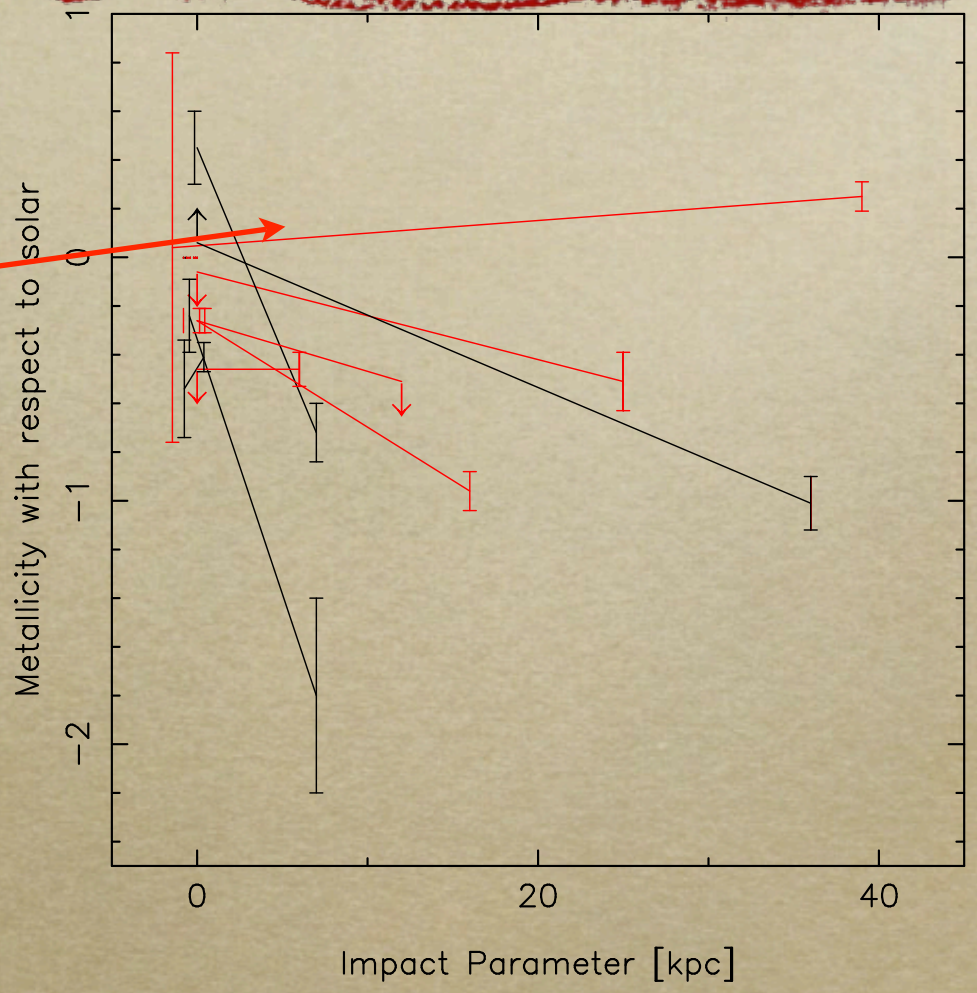


(Peroux, Bouche et al. 2011a)

Metallicity Gradient

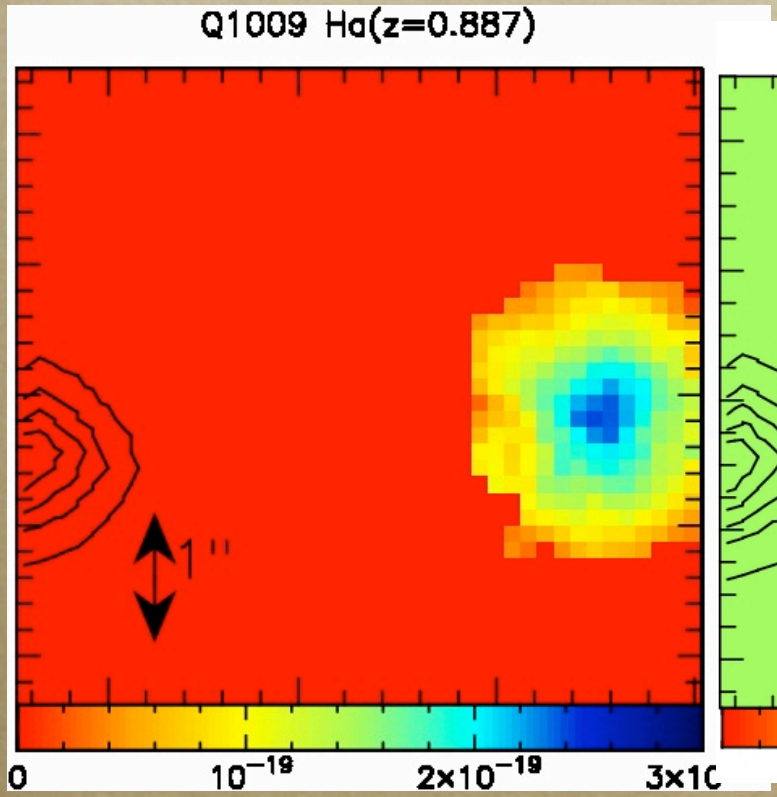
- *this survey more than double number of systems for which such measures are possible*

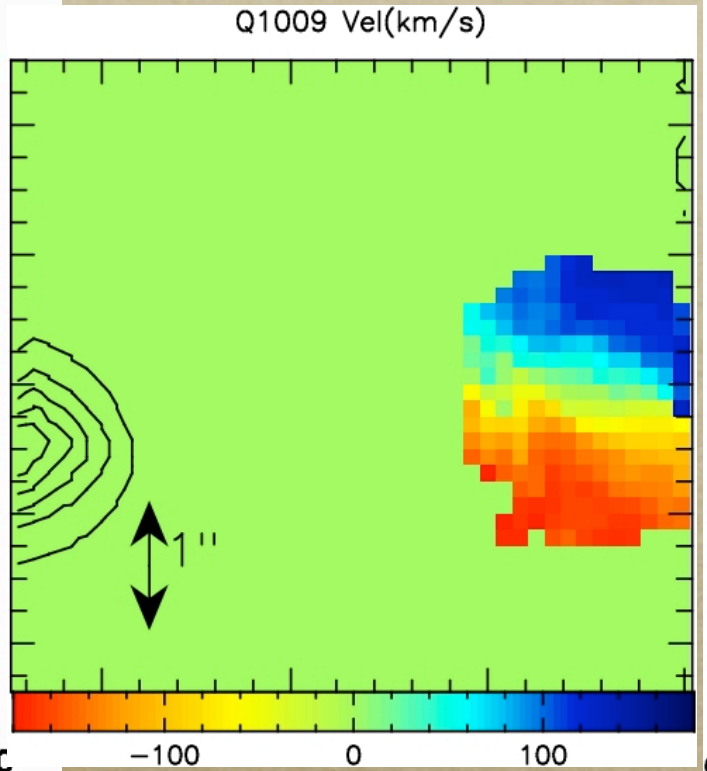
- *'inverted' gradient*
  - due to poor N2 metallicity indicator or
  - difference neutral/ionised gas

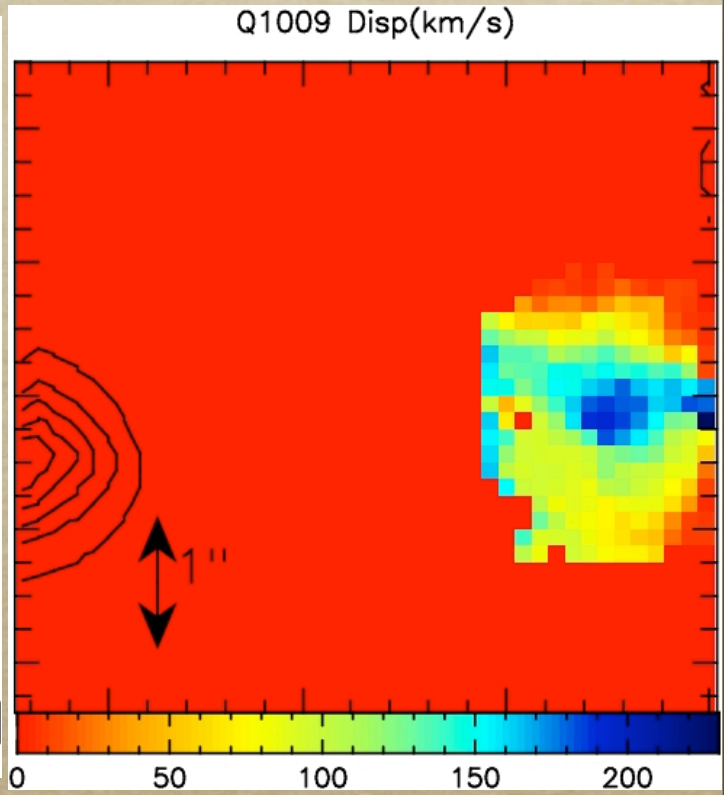


(Peroux, Bouche et al. 2011c)

Kinematics





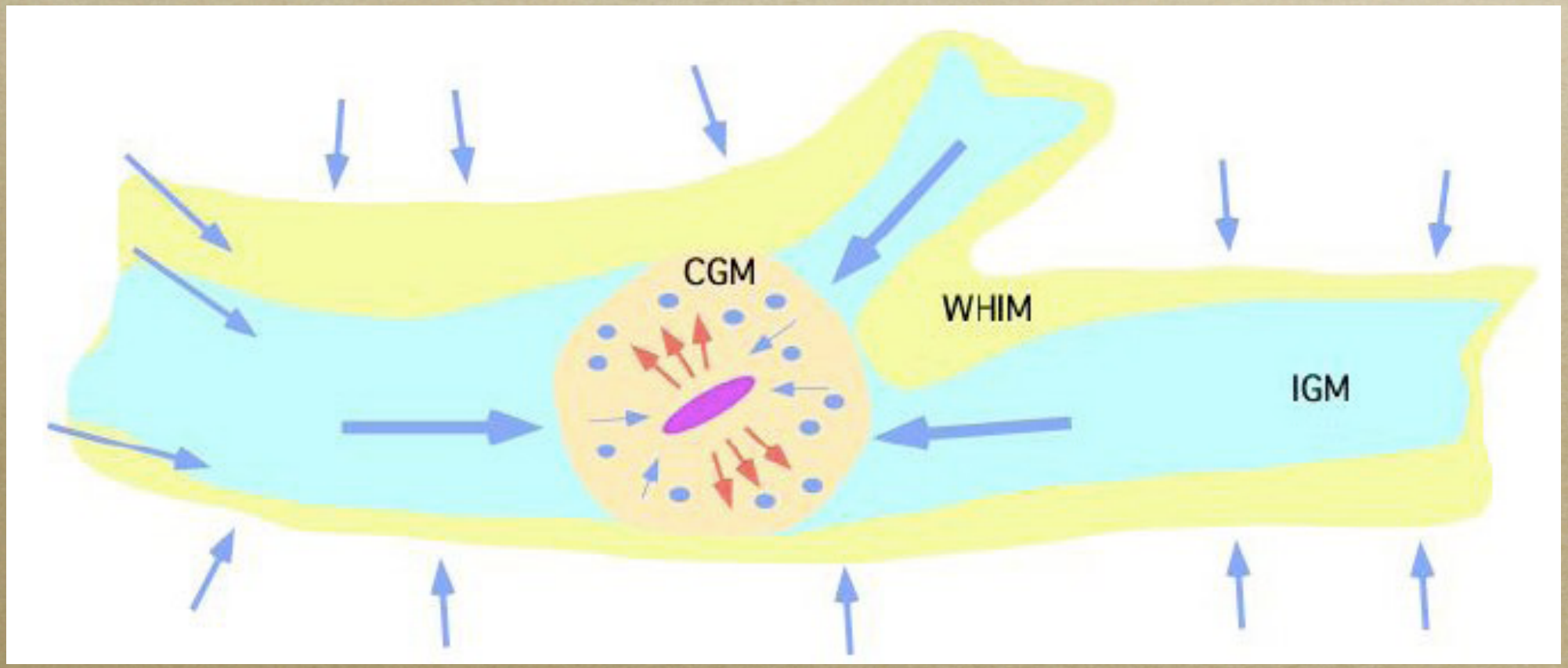


compare rotation curve and absorption profile

(Peroux, Bouche et al. 2011b)

Galaxies/IGM co-Evolution

- *CGM = Circum-Galactic Medium*



Conclusion

- *Galaxy evolution studies need to take into account interactions with the InterGalactic Medium*