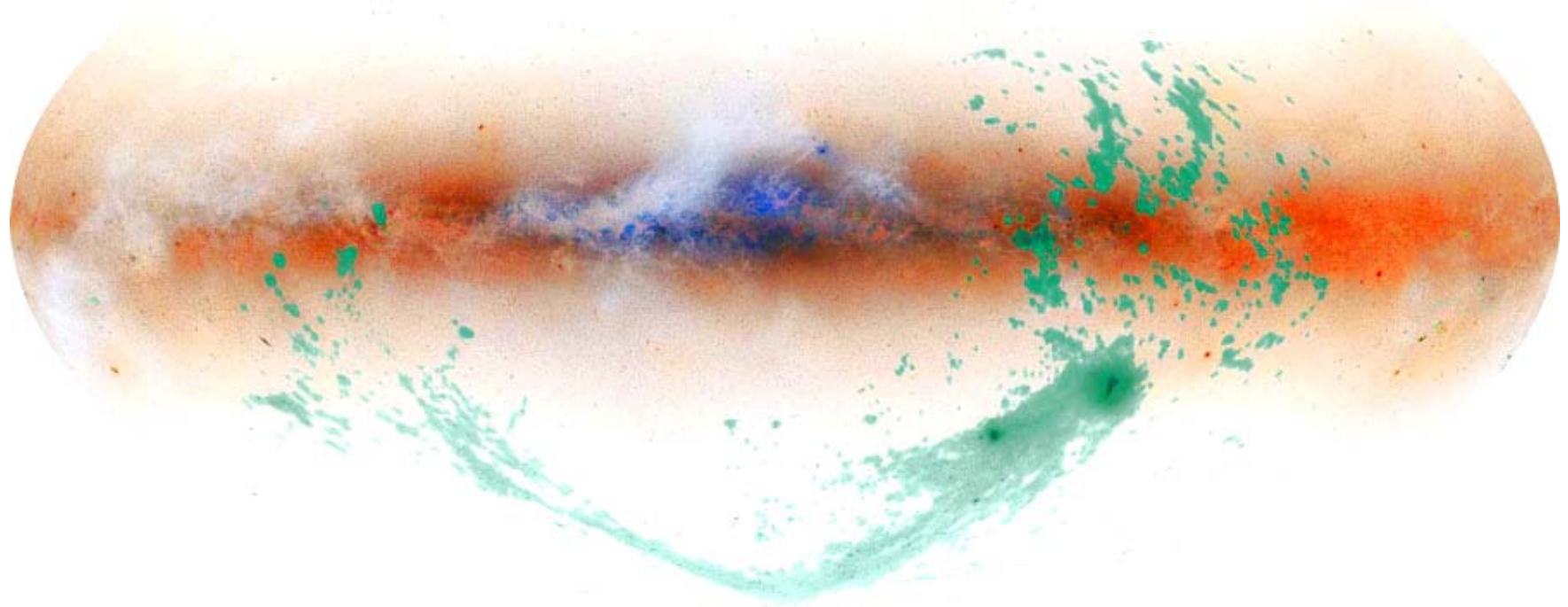
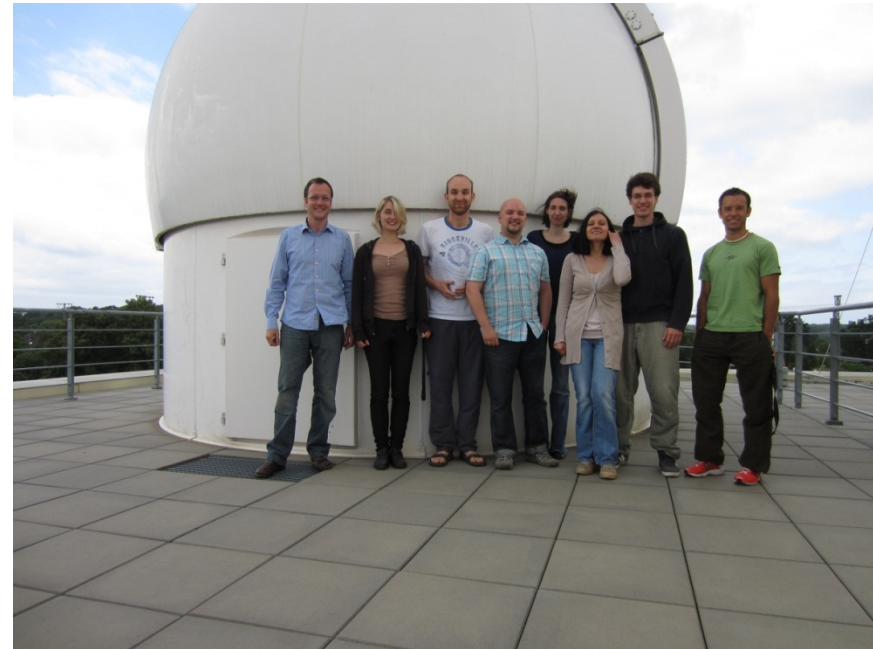


# News on the very local CGM and IGM



**Philipp Richter**  
Potsdam University

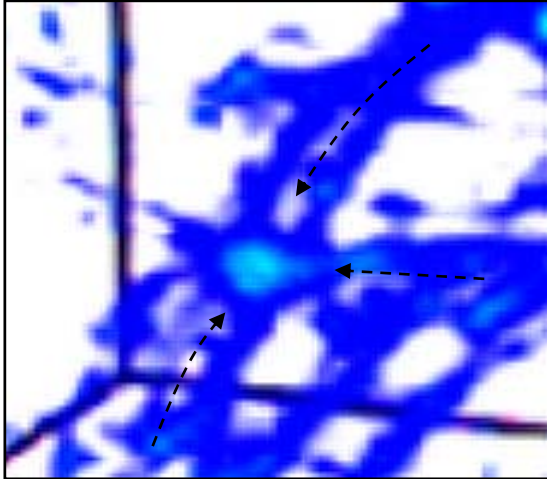
# Physics & Astronomy department at Potsdam University



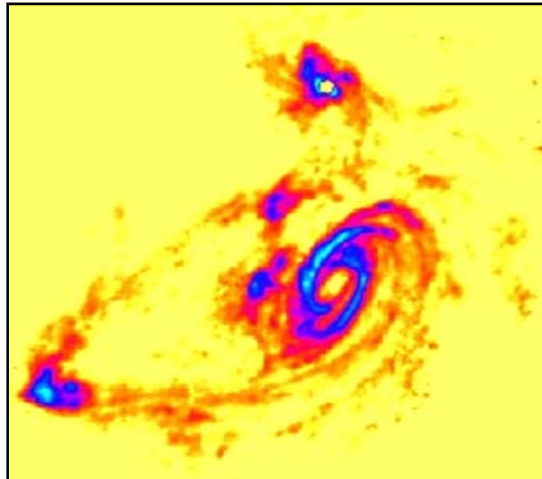
## Astrophysics II

Philipp Richter, Anne Fox, Peter Herenz, Martin  
Wendt, Cora Fechner, Nadia Draganova,  
Dominik Hildebrandt, Thorsten Tepper-García

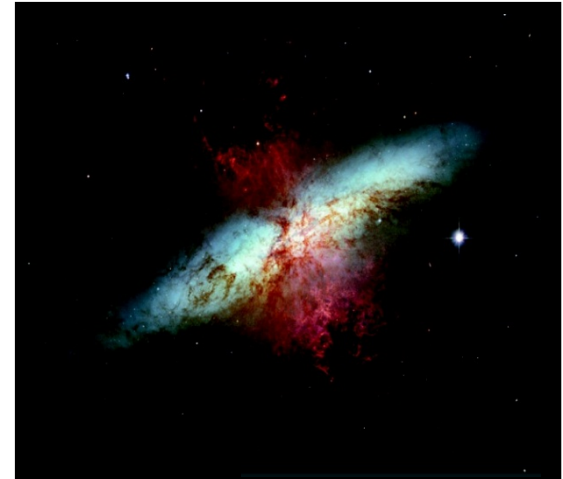
## Gas circulation processes at large scales



**Gas accretion from the intergalactic medium** fuels star formation in galaxies (gas accretion rate  $\sim$  star formation rate in galaxies).



**Galaxy mergers** transport large amounts of interstellar gas into the intergalactic environment of galaxies.

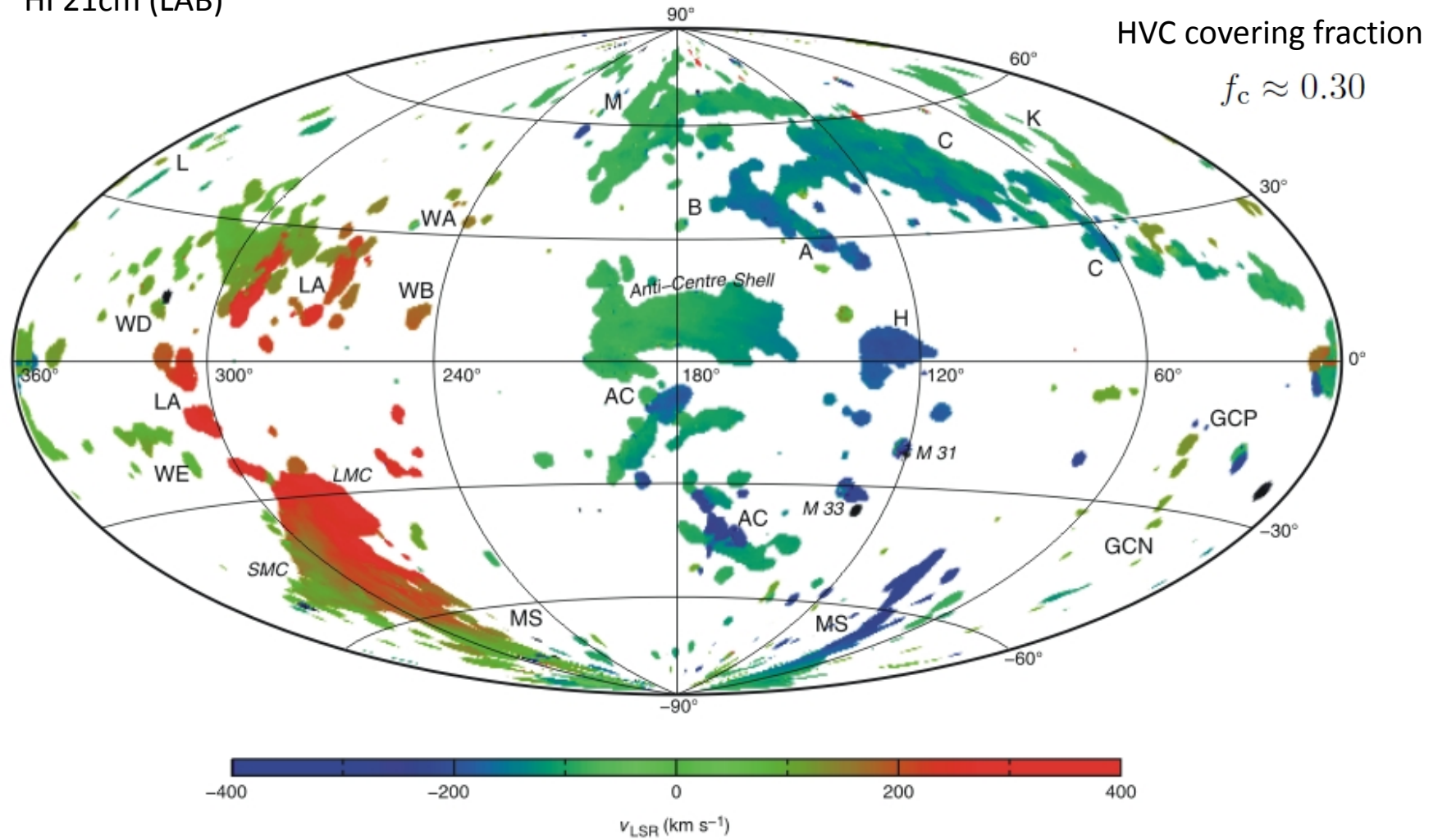


**Galactic winds and fountain-like processes** drive out chemically enriched gas into the IGM and indicate star formation activity in galaxies.

# High-Velocity Clouds

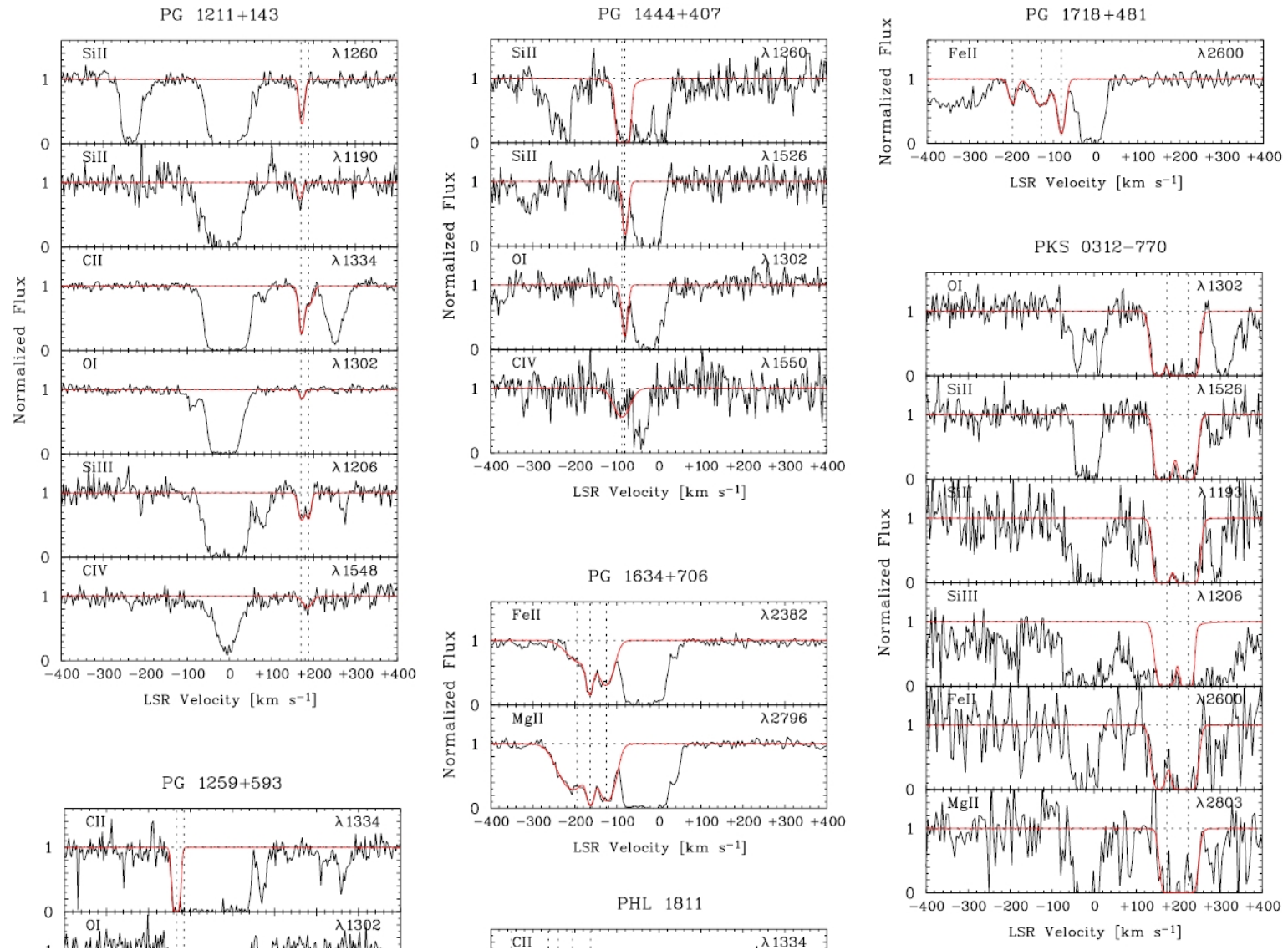
# Galactic high-velocity clouds

HI 21cm (LAB)



(T. Westmeier & P. Kalberla 2008; Richter et al. 2001, 2003, 2009; Wakker et al. 2007, 2008; Fox et al. 2010)

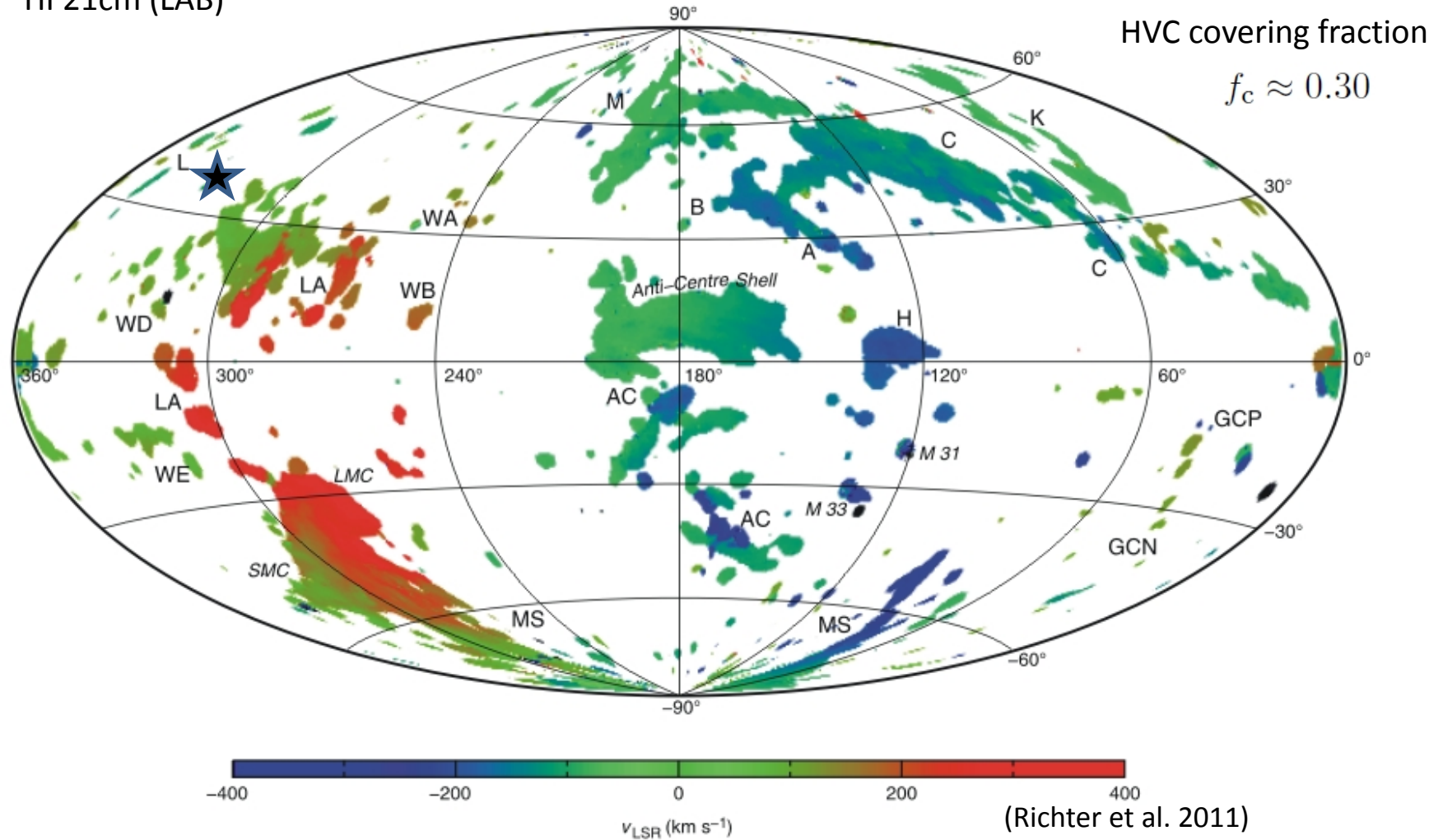
# HVC absorption-line catalogue from HST/STIS



(Herenz et al. 2012)

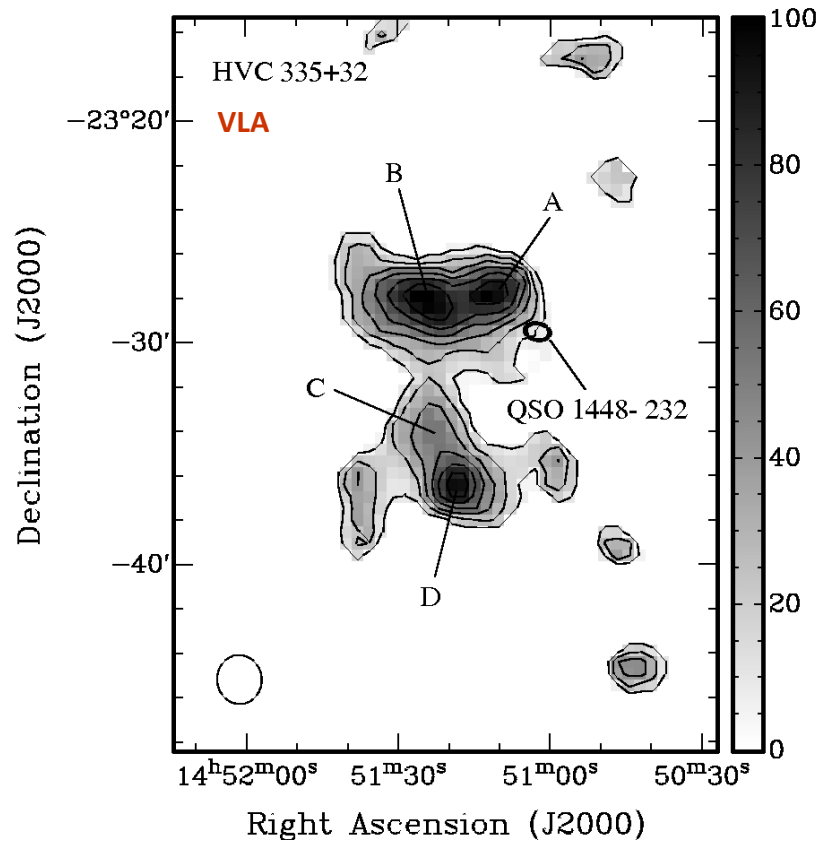
# Galactic high-velocity clouds

HI 21cm (LAB)

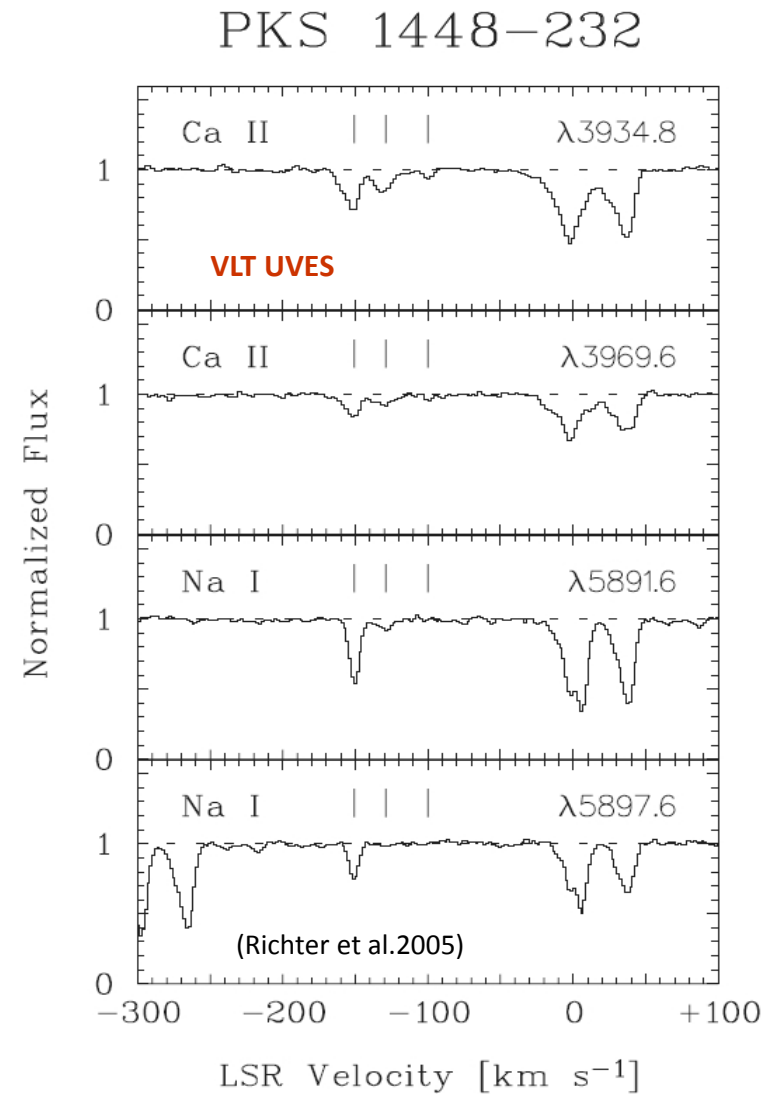


(T. Westmeier & P. Kalberla 2008; Richter et al. 2001, 2003, 2009; Wakker et al. 2007, 2008; Fox et al. 2010)

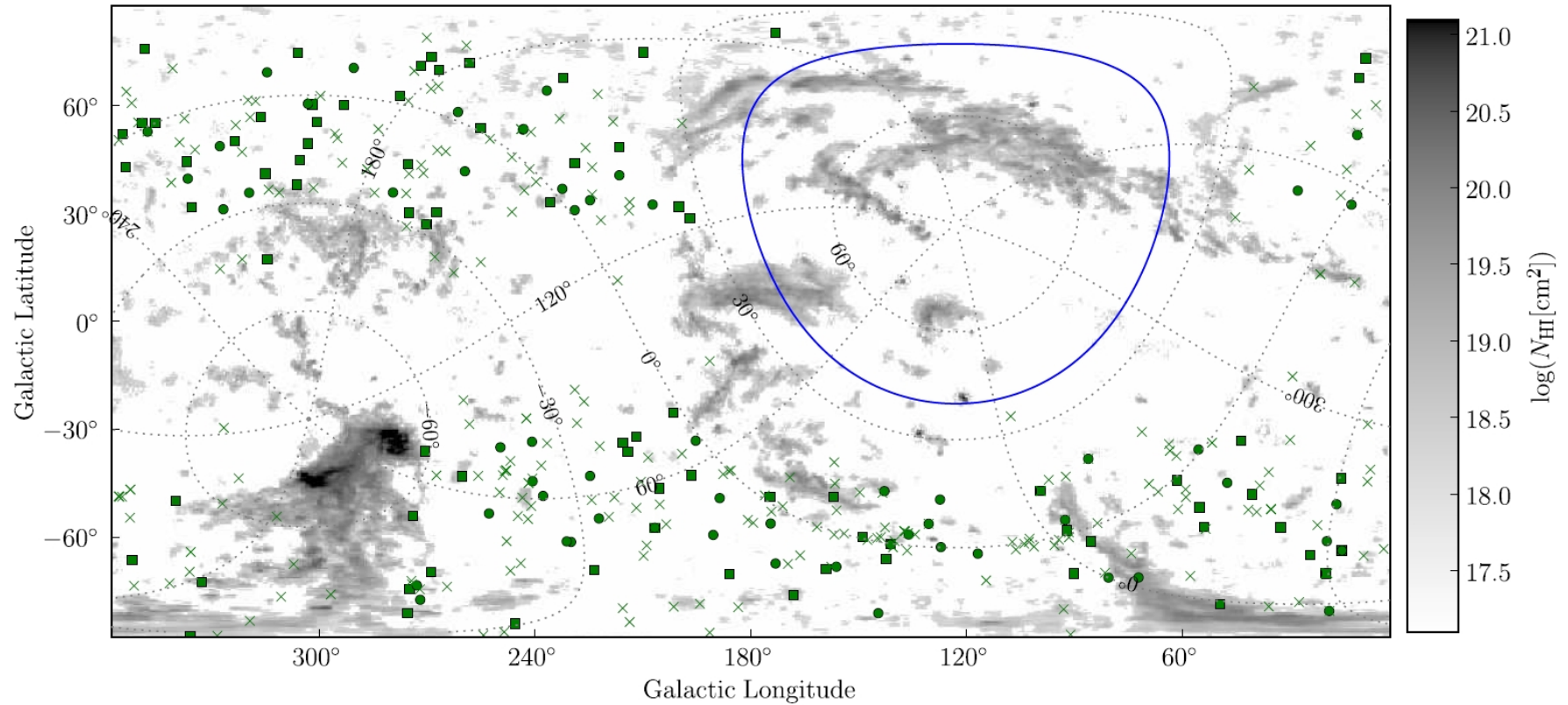
# Optical absorption in Milky Way HVCs



- $N(\text{HI}) < 8 \times 10^{18} \text{ cm}^{-2}$
- Cold ( $T < 900 \text{ K}$ ), small (pc-scale)



# VLT/UVES survey of CaII in IVCs and HVCs

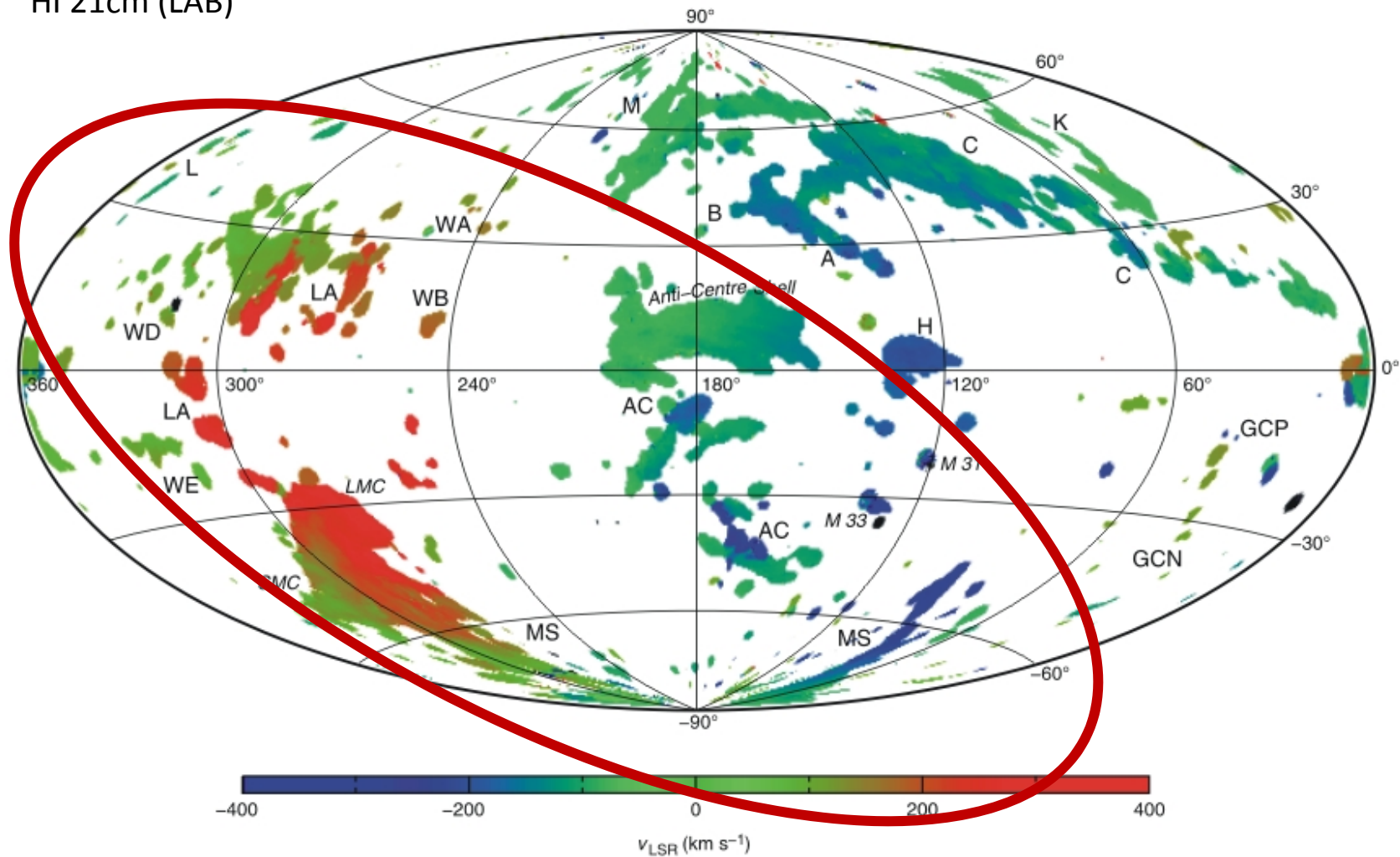


Search for CaII/NaI/TiII absorption in Galactic IVCs and HVCs at  $R > 40,000$  along **408 extragalactic lines of sight** (Ben Bekhti et al. 2012).

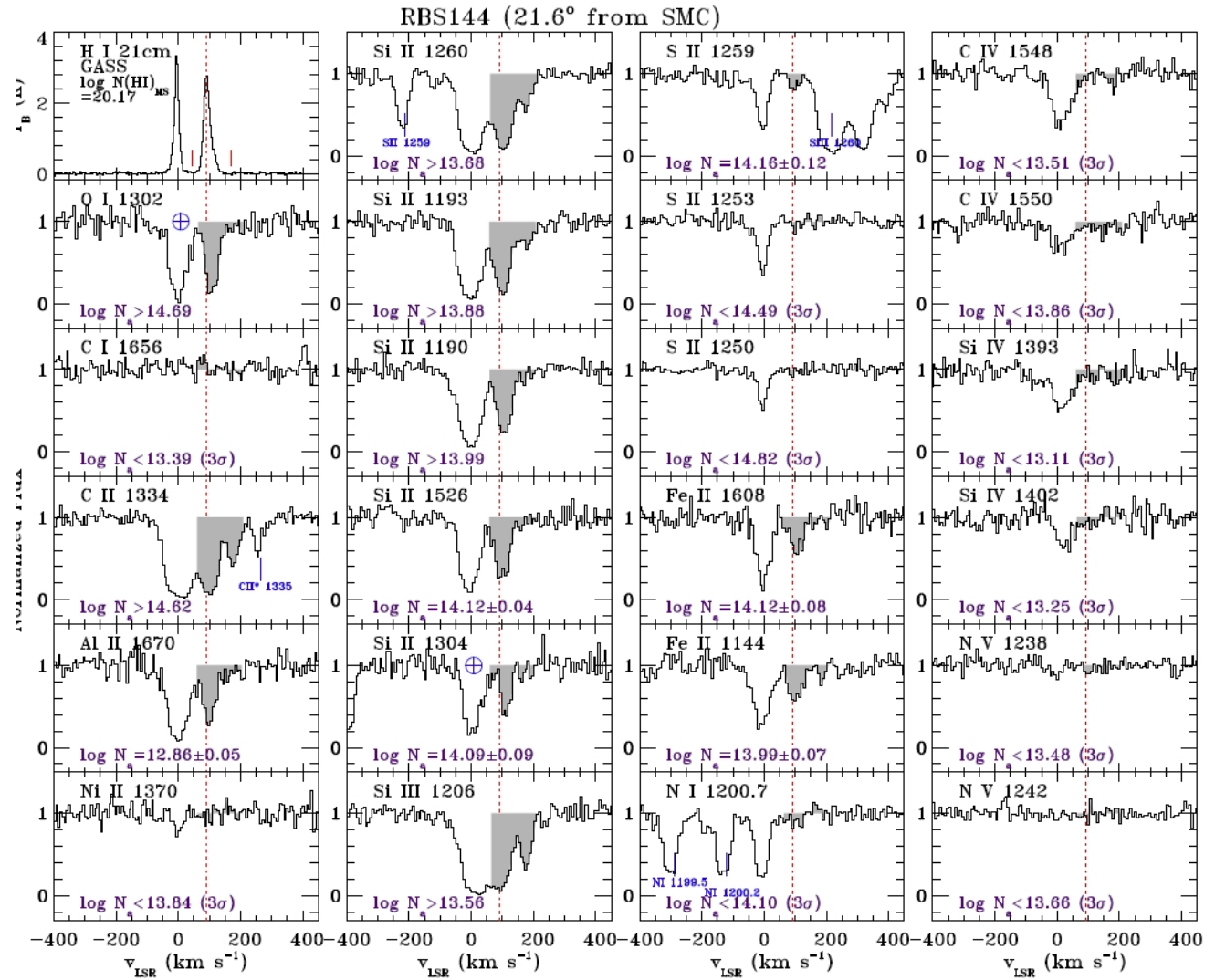
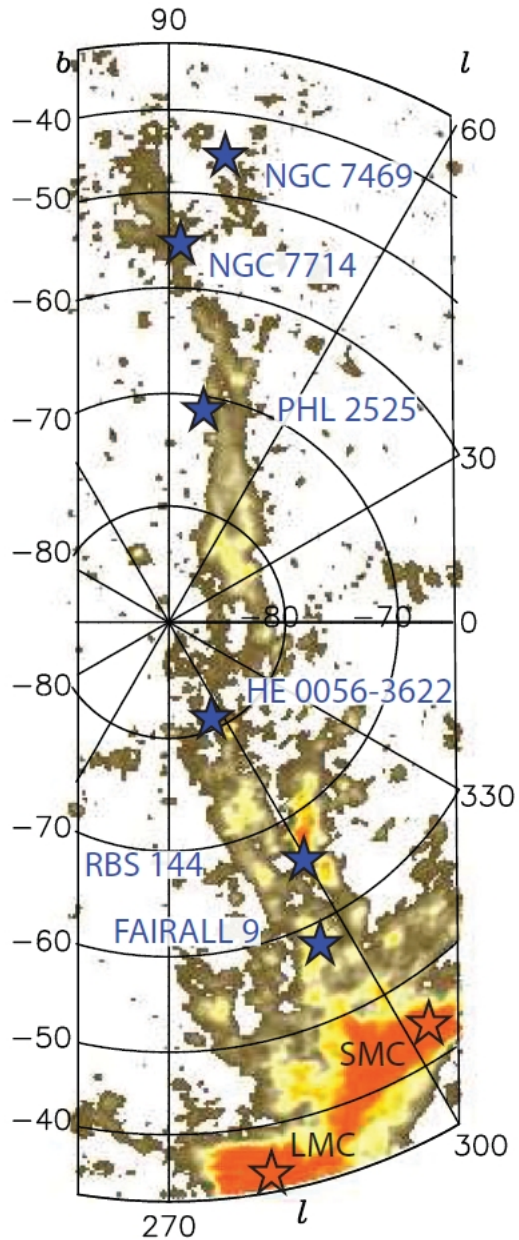
# The Magellanic Stream

# Magellanic Stream VLT/UVES + HST/COS survey

HI 21cm (LAB)



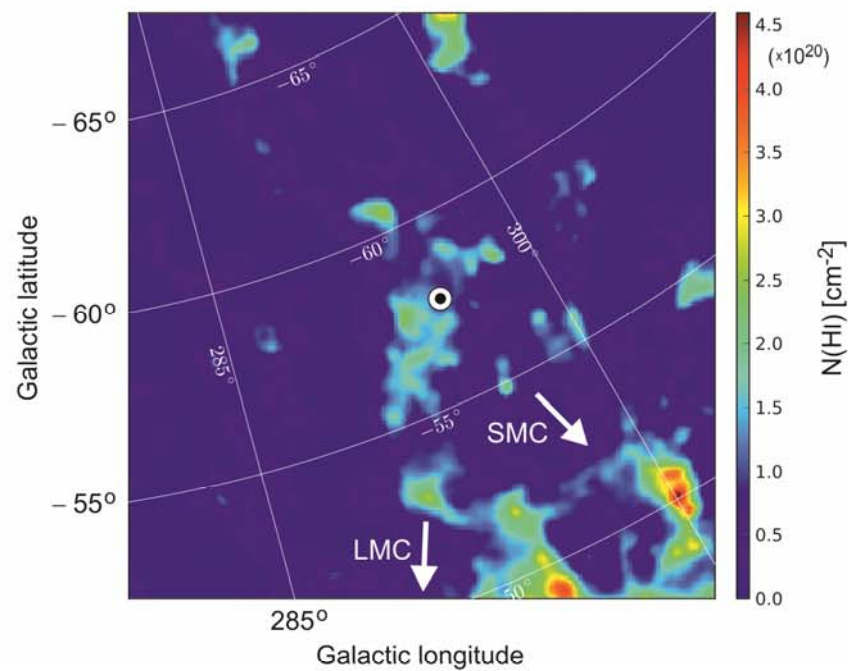
# Magellanic Stream VLT/UVES + HST/COS survey



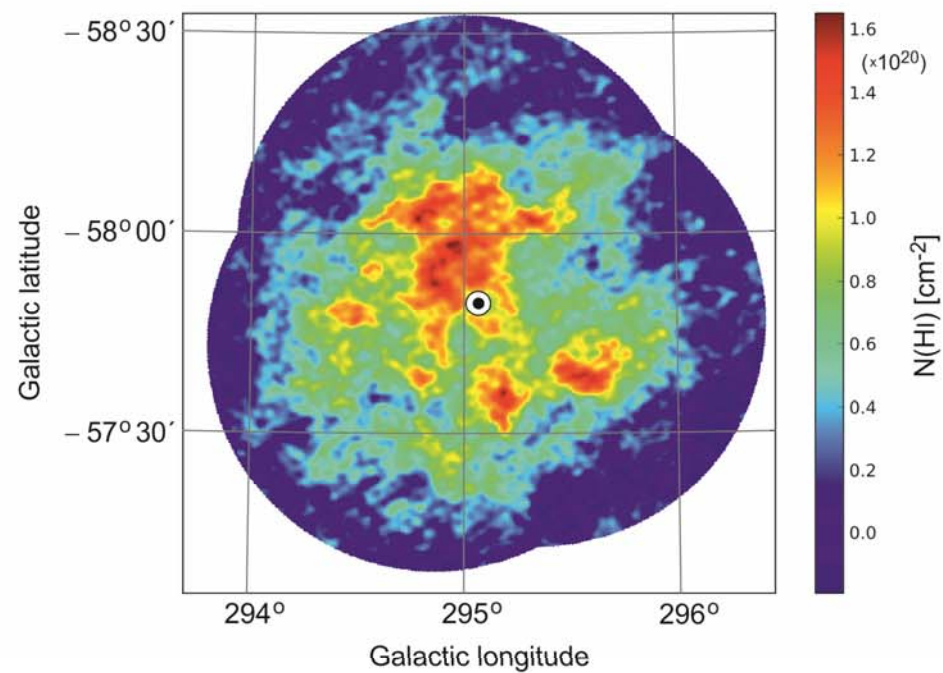
(Fox et al. 2013)

# Magellanic Stream VLT/UVES + HST/COS survey

## The Fairall 9 sightline:



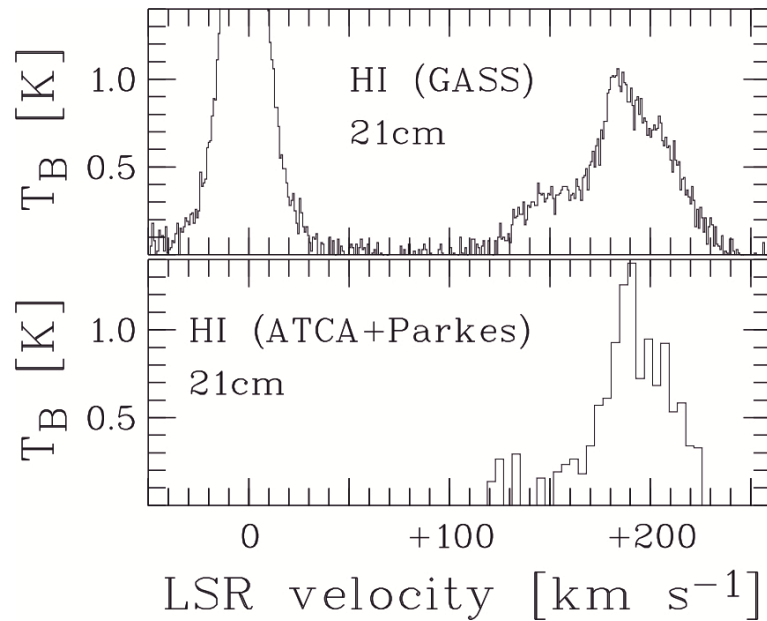
HI 21cm (GASS)



HI 21cm (ATCA)

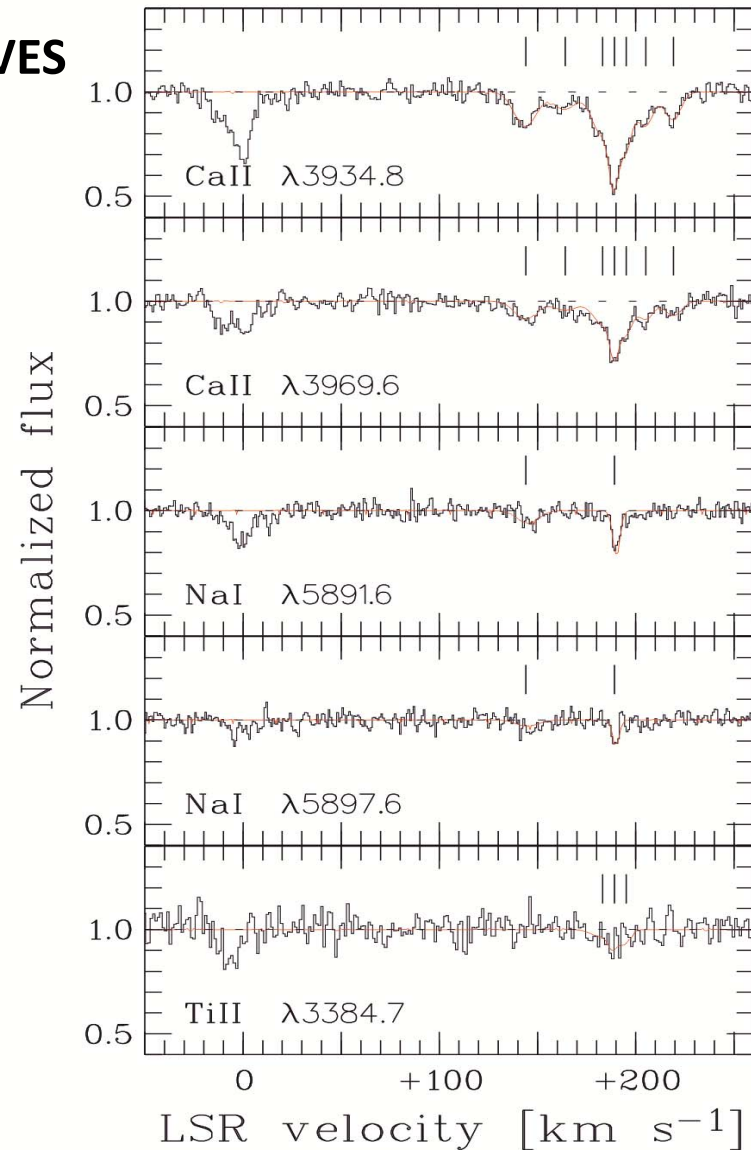
# Magellanic Stream VLT/UVES + HST/COS survey

The Fairall 9 sightline:



Optical spectra indicate  
highly complex absorption-  
component structure

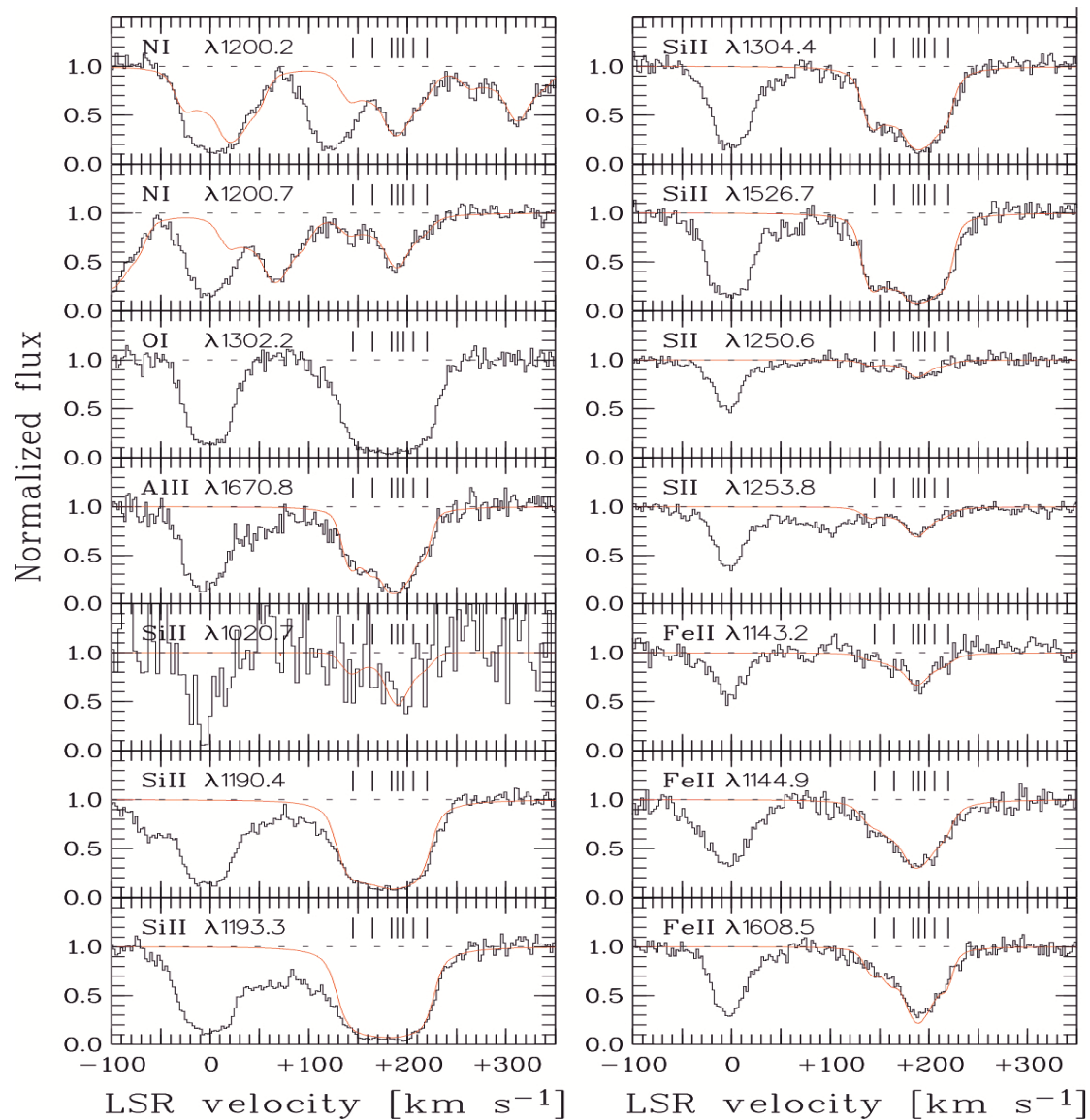
VLT/UVES



# Magellanic Stream VLT/UVES + HST/COS survey

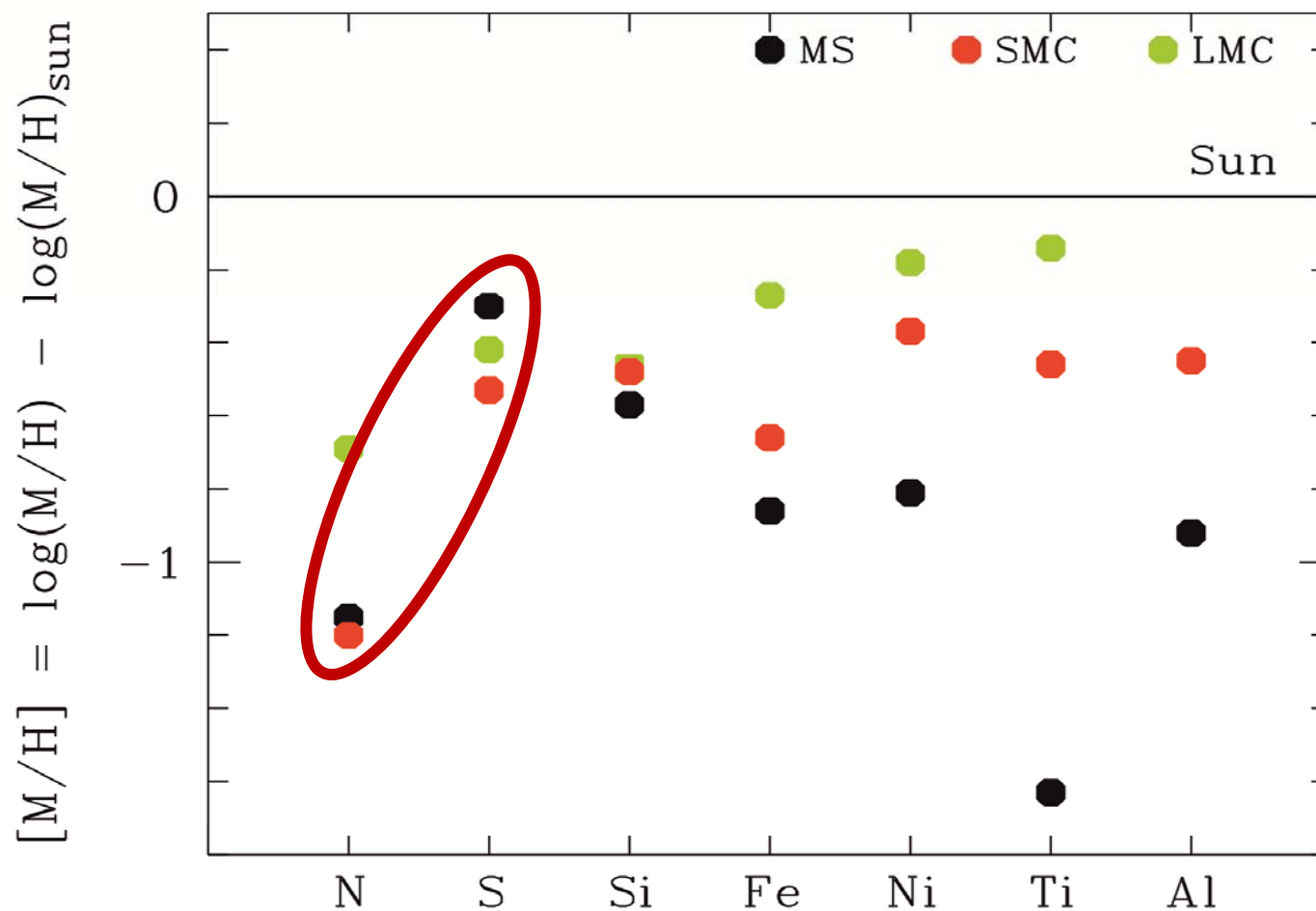
The Fairall 9 sightline:

HST/COS



# Magellanic Stream VLT/UVES + HST/COS survey

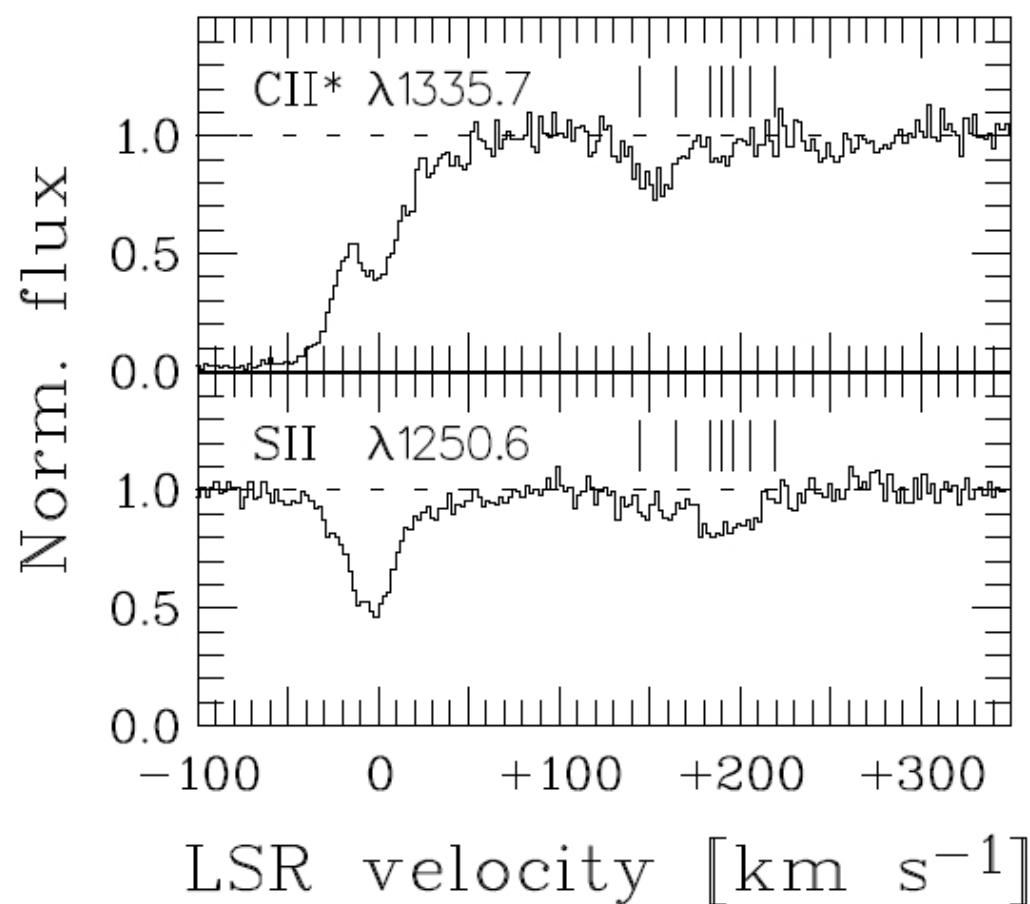
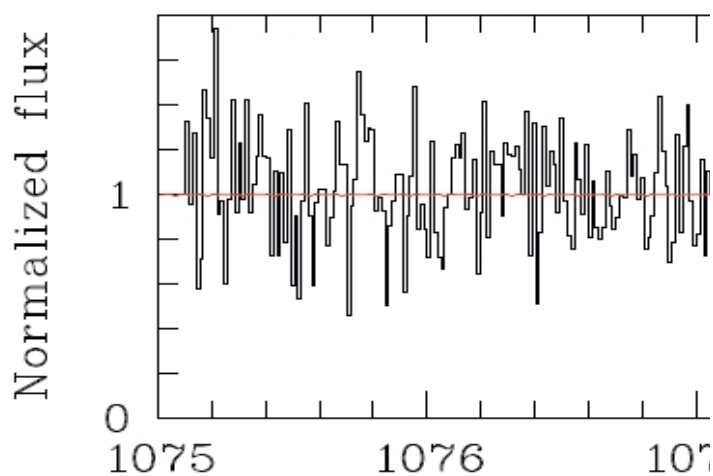
The Fairall 9 sightline:



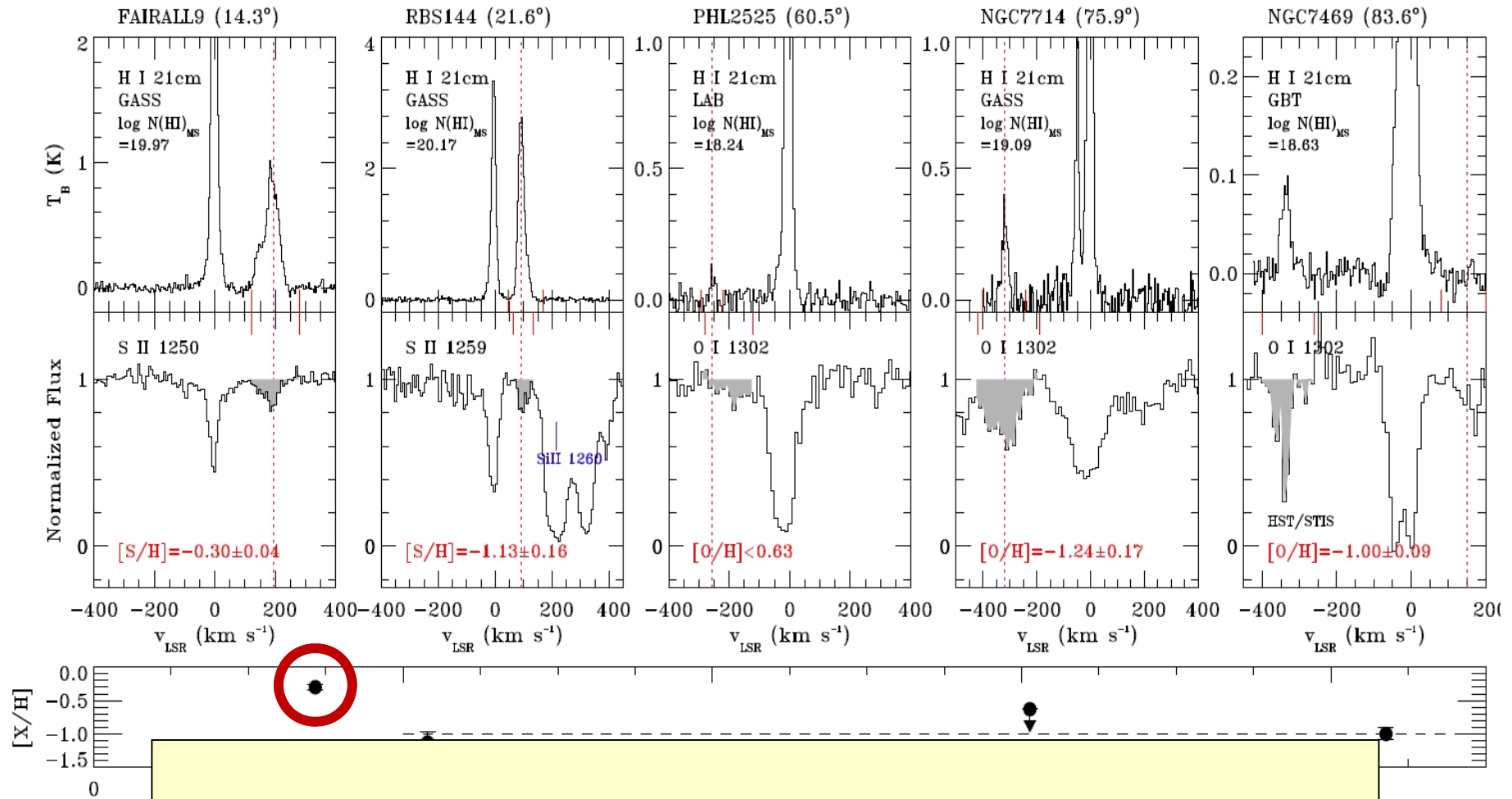
(Richter et al. 2013)

# Magellanic Stream VLT/UVES + HST/COS survey

## The Fairall 9 sightline: $\text{H}_2$ and $\text{CII}^*$ absorption in the Stream



# Summary: $\alpha$ -abundance measurements in the Stream



**Magellanic Stream probably contains material  
from SMC AND LMC !**

# Magellanic Stream VLT/UVES + HST/COS survey

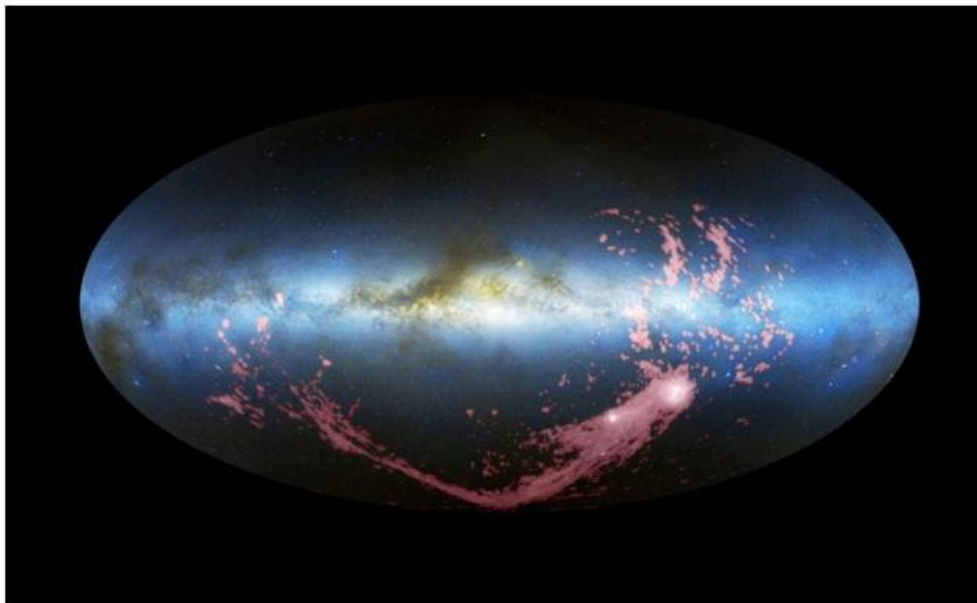
NATURE | NEWS

## Giant band of galactic gas likely has dual origin

Two satellites of the Milky Way contributed to the Magellanic Stream.

Ken Croswell

21 May 2013



The Magellanic Stream, a band of gas (pink in this false-color image) that sweeps across part of the sky around the Milky Way (horizontal light-blue band), originates in part from the interaction of the two Magellanic Clouds (white regions at bottom right).

NIDEVER, ET AL., *NRAO/AUINSF AND MELLINGER, LEIDEN-ARGENTINE-BONN SURVEY, PARKES OBSERVATORY, WESTERBORK OBSERVATORY, ARECIBO OBSERVATORY.*

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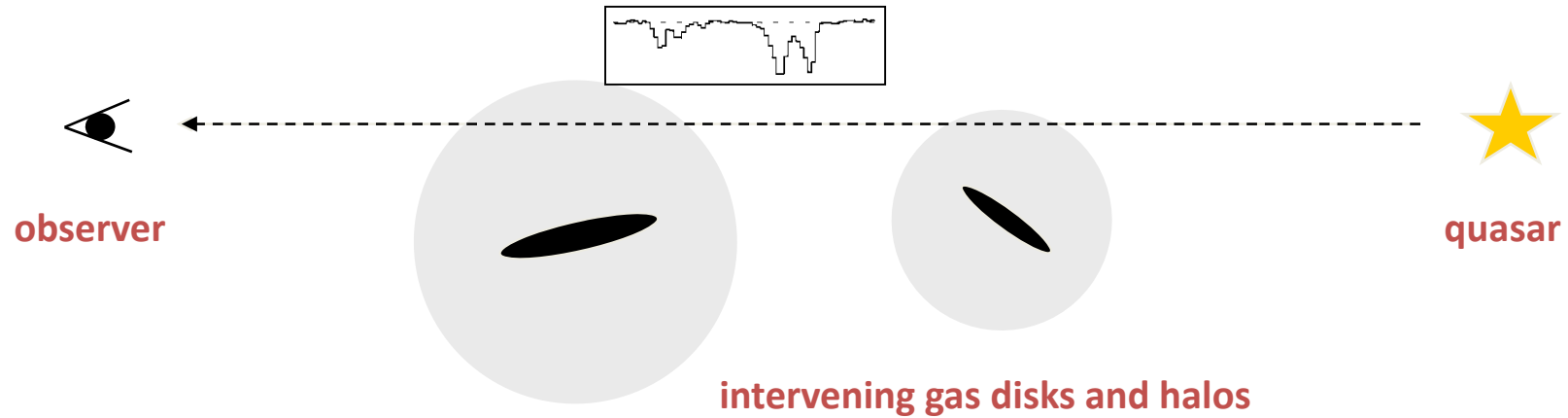
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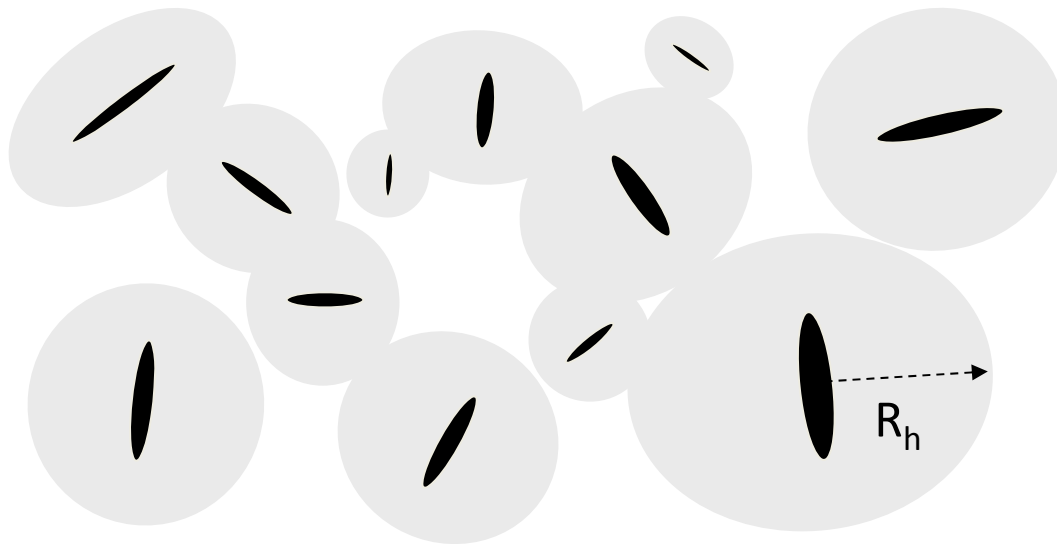
 **MACMILLAN**  
SCIENCE COMMUNICATION

The neutral gas distribution around galaxies

# Galaxy halos traced by intervening QSO absorption systems



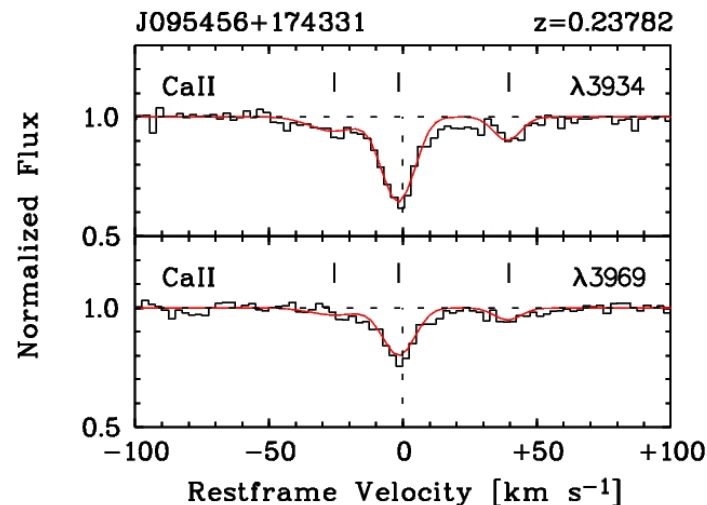
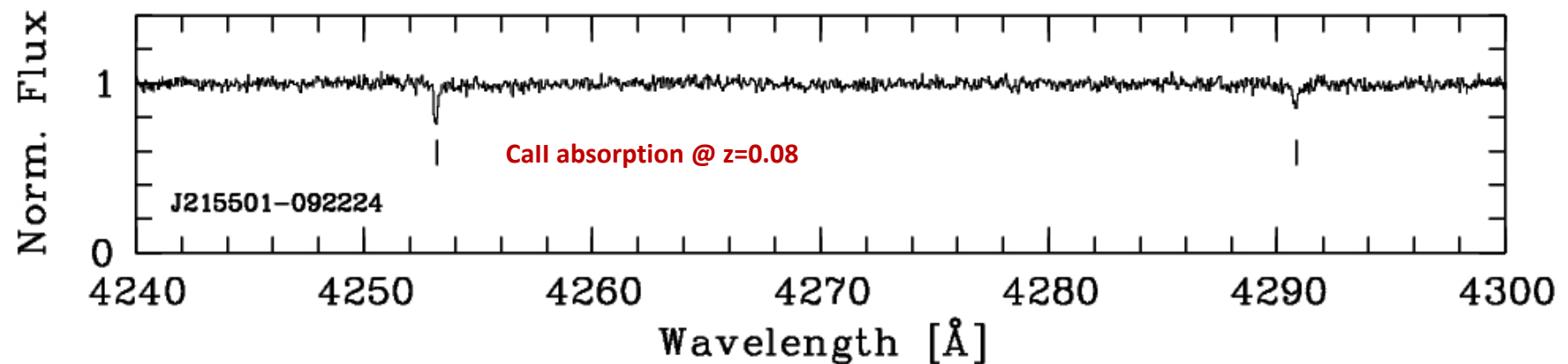
resulting projected absorption cross section HI gas in halos:



$$\frac{d\mathcal{N}}{dz} = \frac{c n_{\text{gal}} \langle A_{\text{HI}} \rangle}{H(z)}$$

# Distant HVC analogs traced by intervening Call absorption systems

Examples from an optical survey (>400 VLT/UVES QSO spectra) of **intervening Call absorbers at  $z < 0.5$**

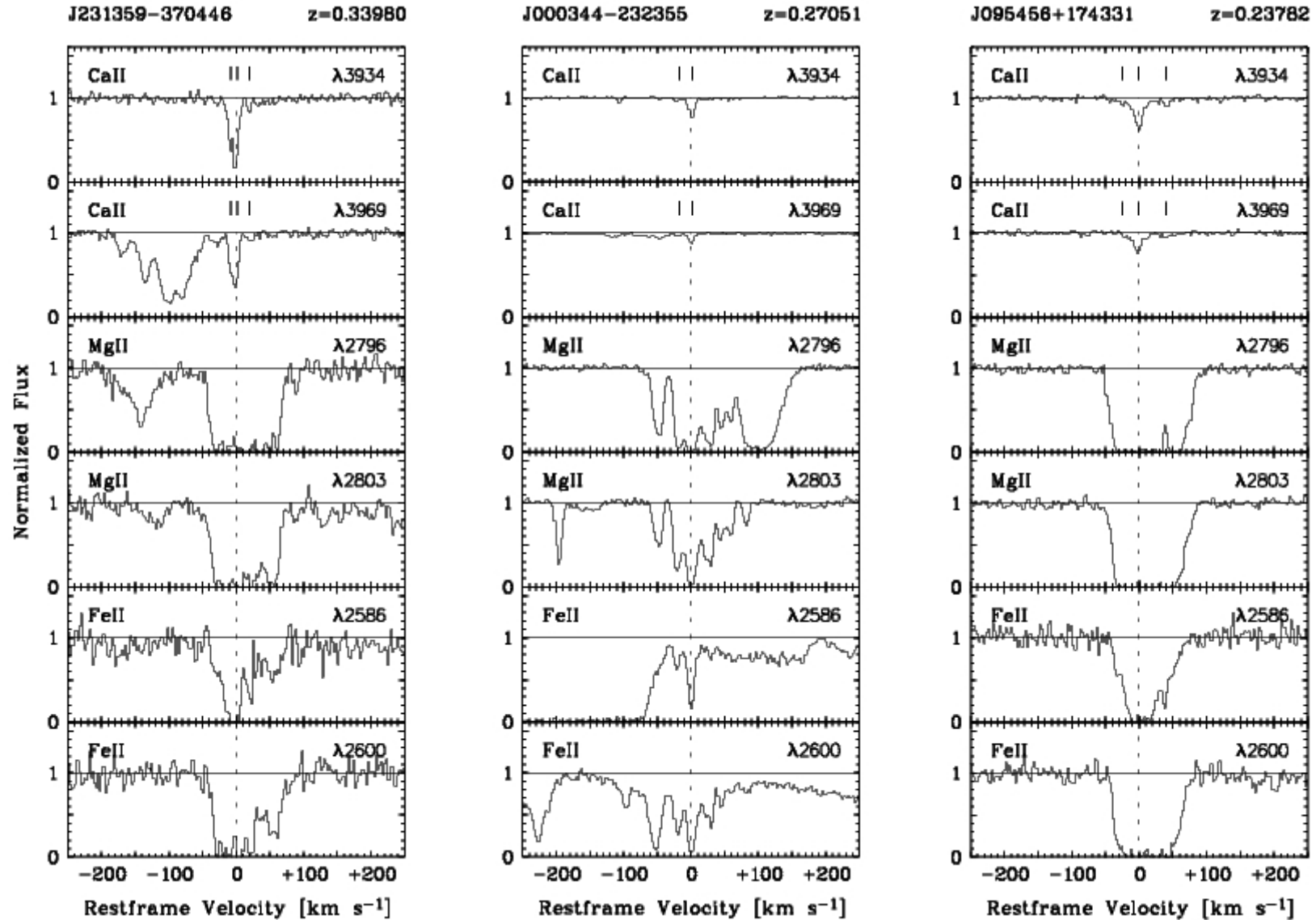


Characteristic extent of HI halos of low- $z$  galaxies:

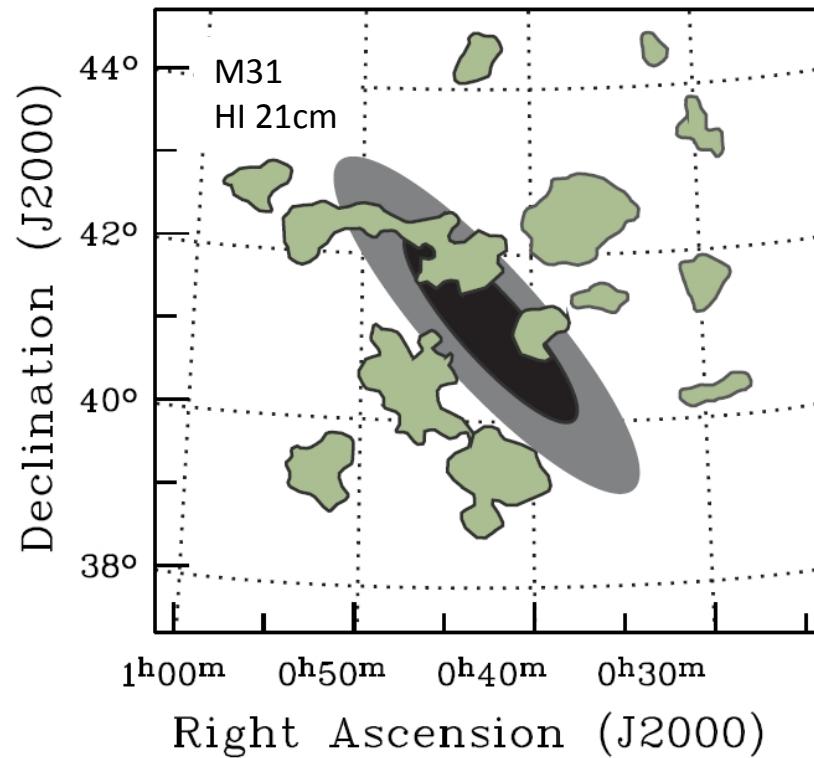
$$\langle R_{\text{HI halo}} \rangle \sim 50 \text{ kpc}$$

(Richter et al. 2011)

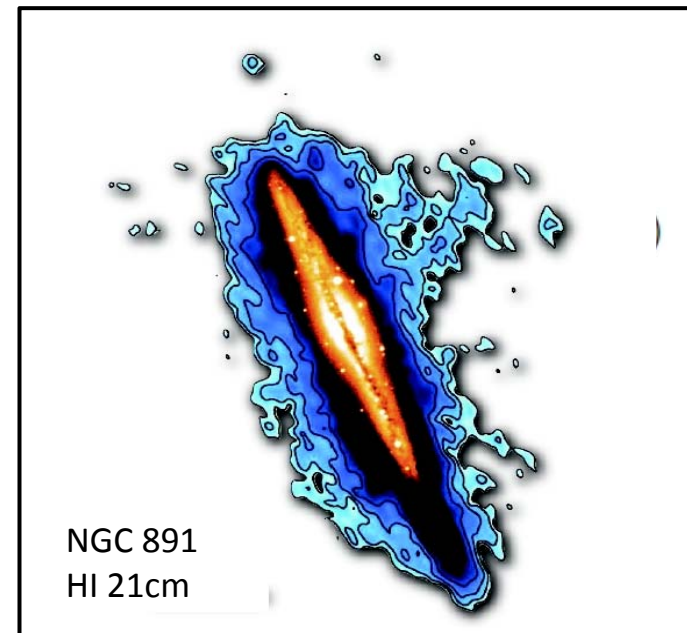
## Examples for intervening Ca II absorbers



## 21cm HVCs around other galaxies: M31 and NGC 891



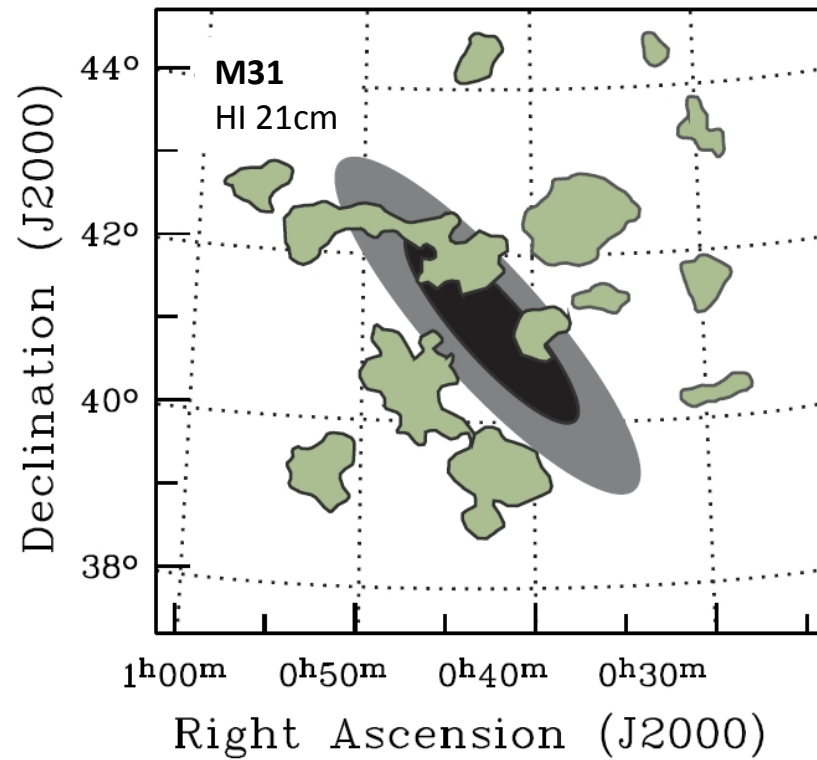
(Thilker et al. 2004)



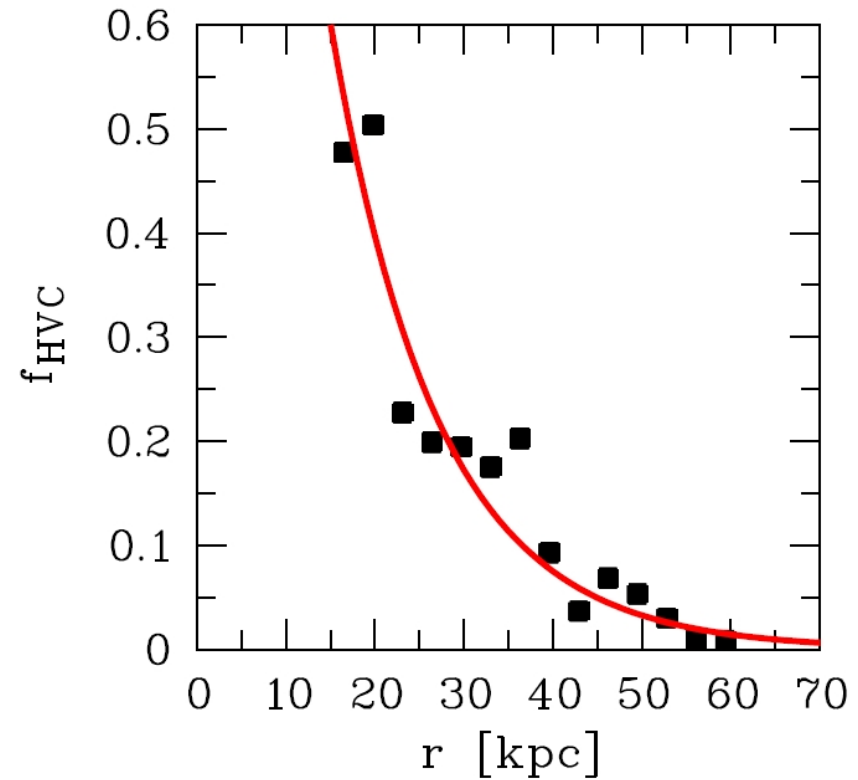
(Oosterloo et al. 2008)

➡ **observational evidence for neutral gas around  $z=0$  spirals**

## HI covering fractions of gas in the halo of M31



(adapted from Thilker et al. 2004)



(Richter 2012)

M31 shows exponential decline of  $f_c(\text{HI})$  in the form  $f_c(\text{HI}) = 2.1 \exp(-r/12)$ .

# Modeling HVC with the HALOPATH code

## Goal:

- estimate of mean covering fractions  $\langle f_c \rangle$  and radial extent  $r_{\text{halo}}$  of different gas phases for galaxies of different *mass*

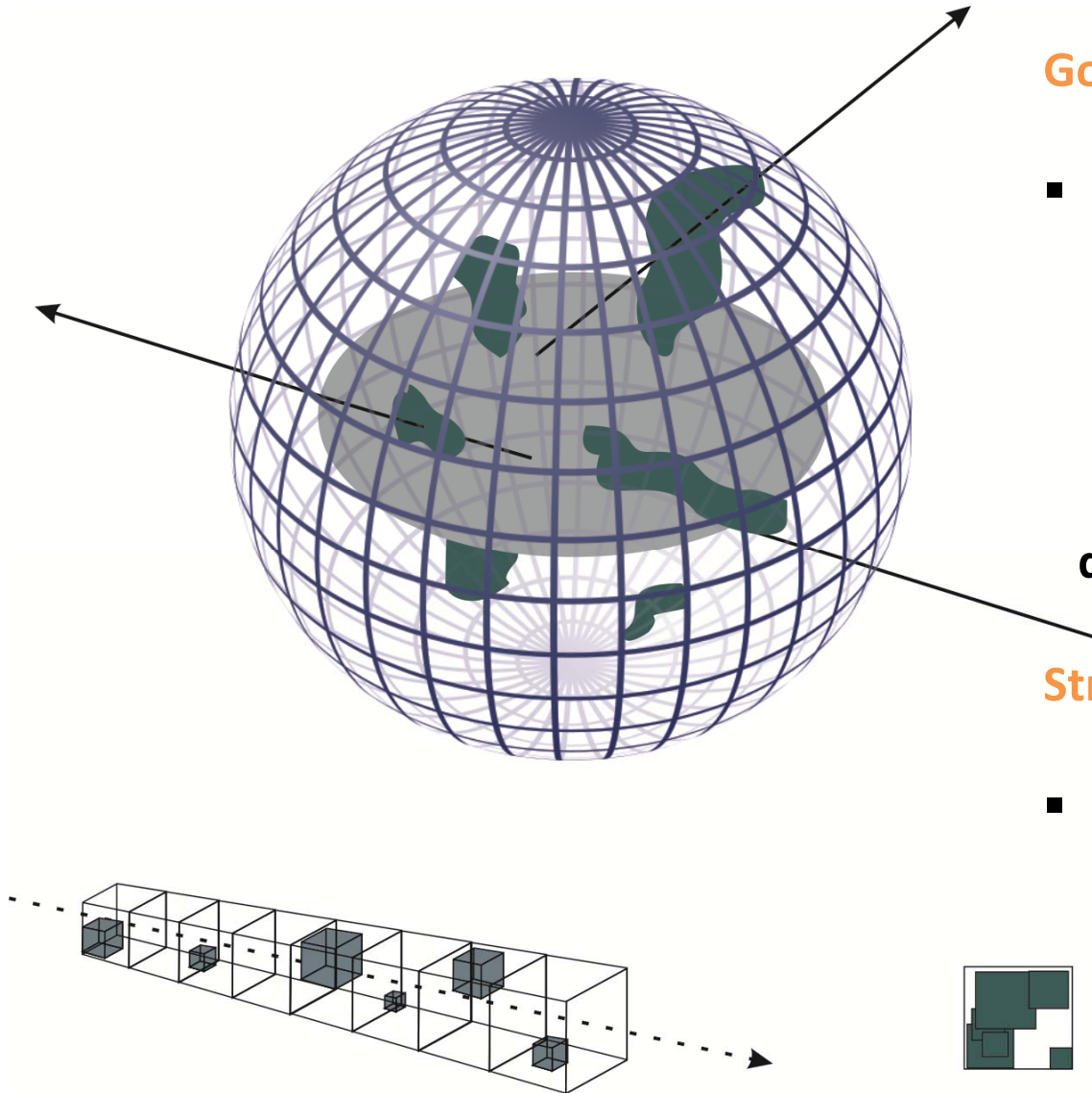


**$dN/dz$  (ion) and  $dM(\text{gas})/dt/dV$**

## Strategy:

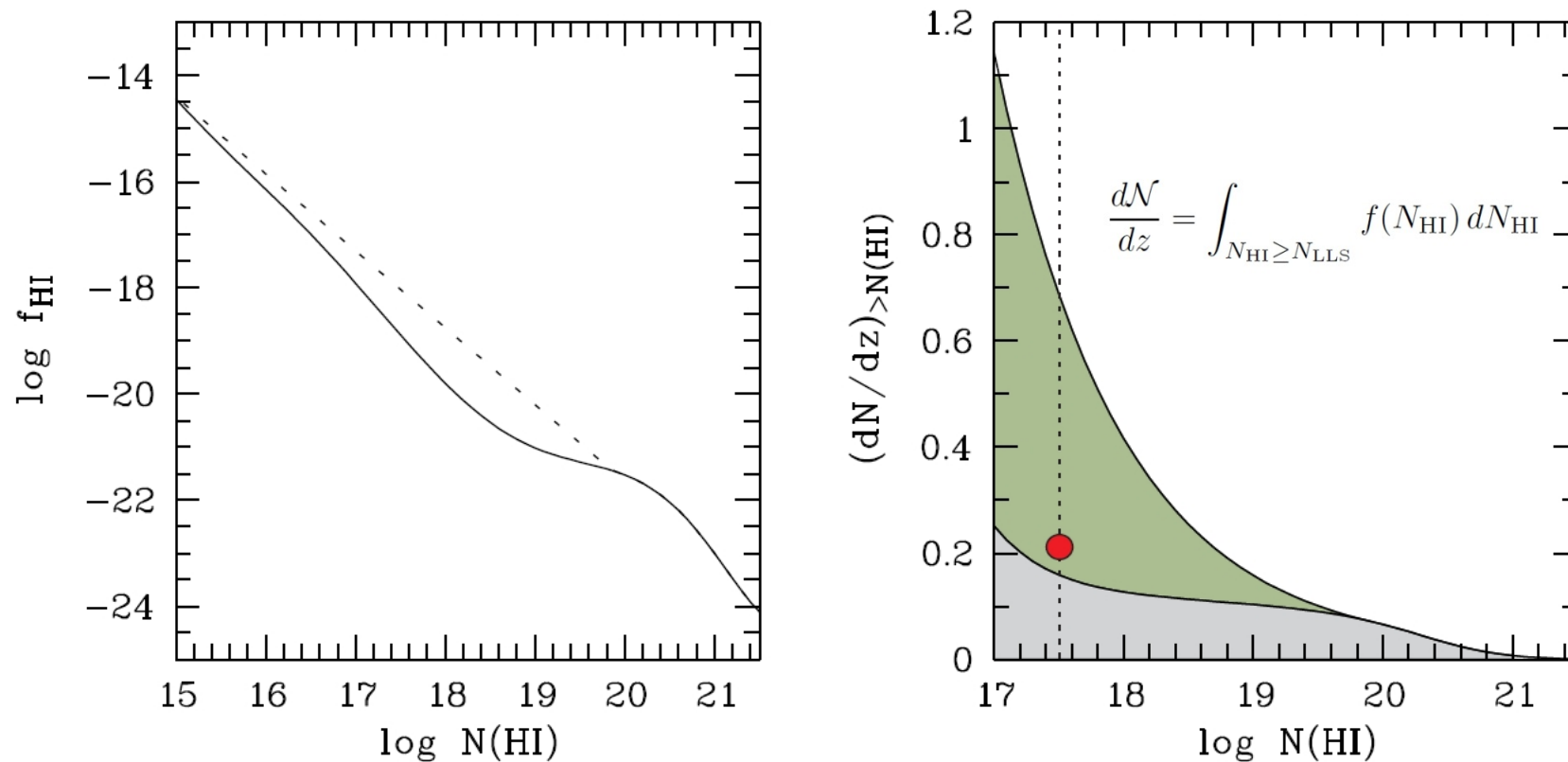
- modeling of gas *volume-filling factors*  $f_v(r)$ , from which all relevant quantities can be derived

(Richter 2012)



## HVCs and their connection to LLS

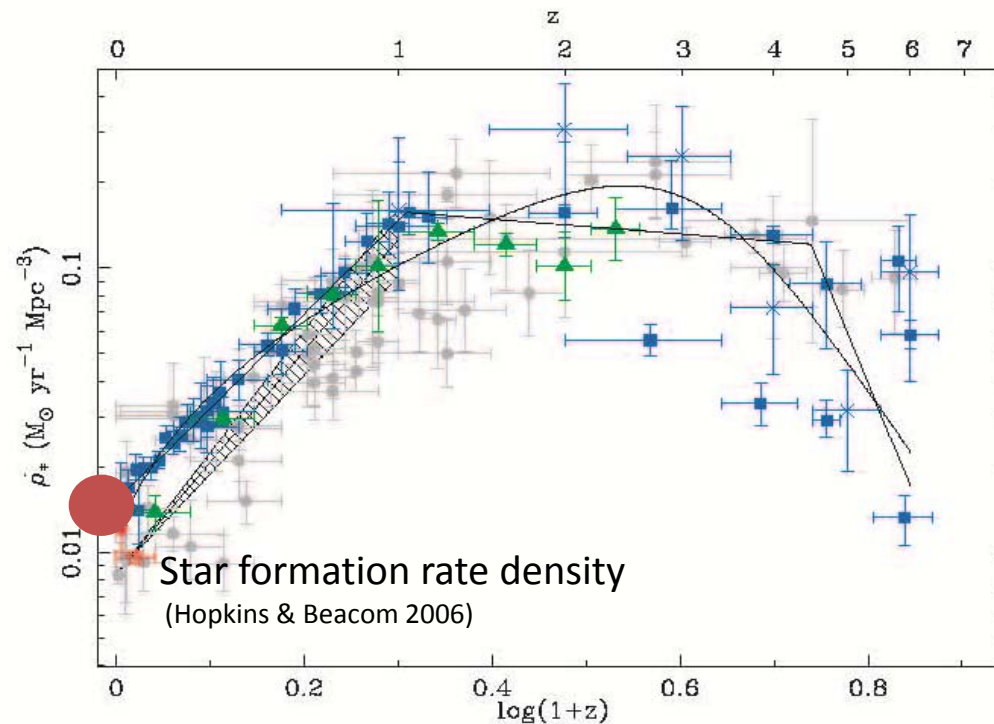
HI column density distribution function at  $z=0$  not well constrained; combination of absorption and emission measurements (Corbelli et al 2002; Zwaan et al. 2005; Lehner et al. 2007).



Milky Way-type HVCs may account for 33-100 percent of the LLS at  $z=0$ .

## HVCs and neutral gas accretion rates

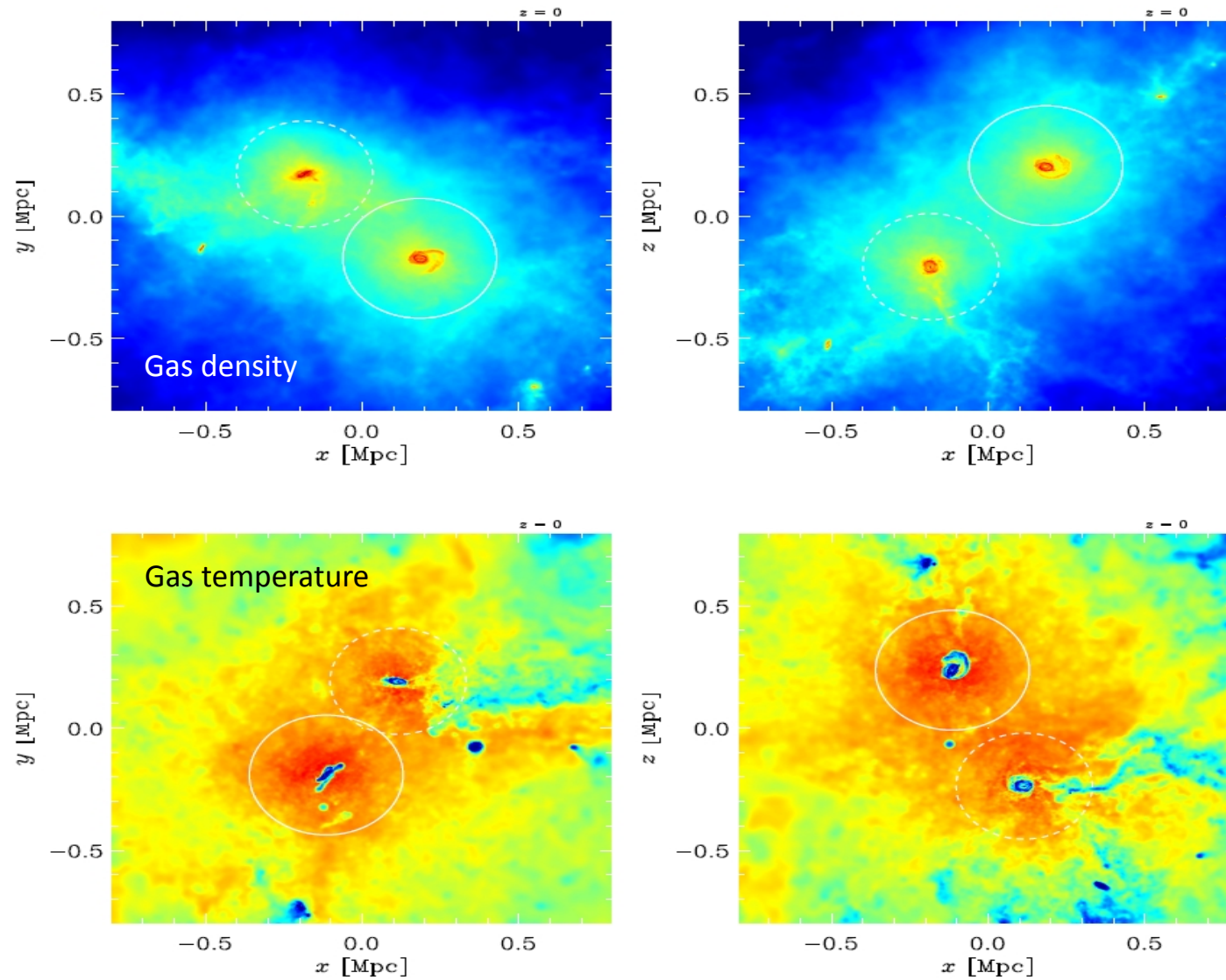
Estimate of the total *cold gas accretion rate density* in the form of HVCs for the local galaxy population:  $\dot{dM}/dt/dV = 0.016 M_{\text{sun}}/\text{yr}/\text{Mpc}^3$



Milky Way-type HVCs probably contribute substantially to the cold-gas accretion rates of low-redshift galaxies.

Simulations of the local CGM and IGM

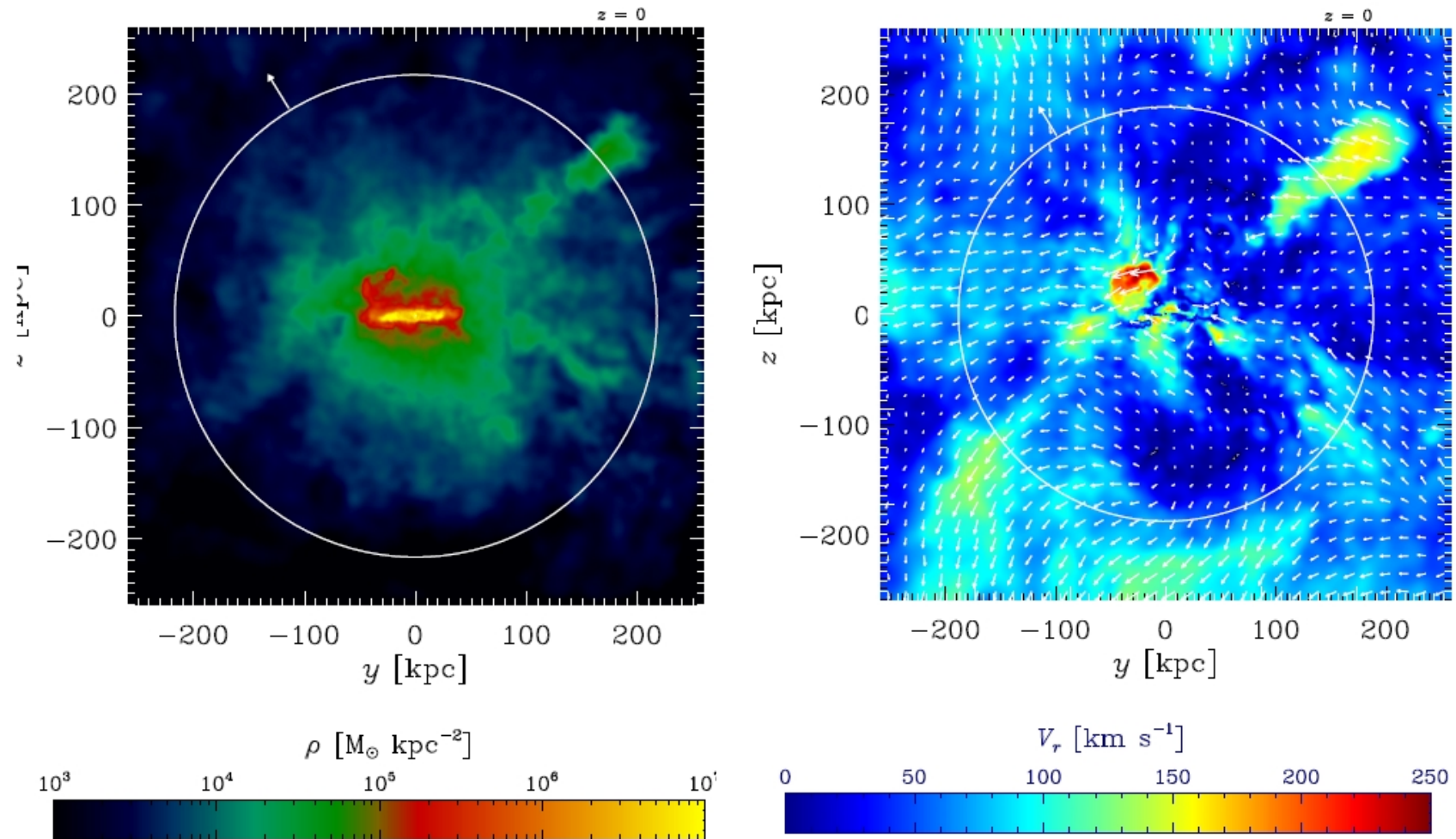
# Constrained simulations of the Local Group with CLUES



(Nuza et al. 2013, in preparation)

# Constrained simulations of the Local Group with CLUES

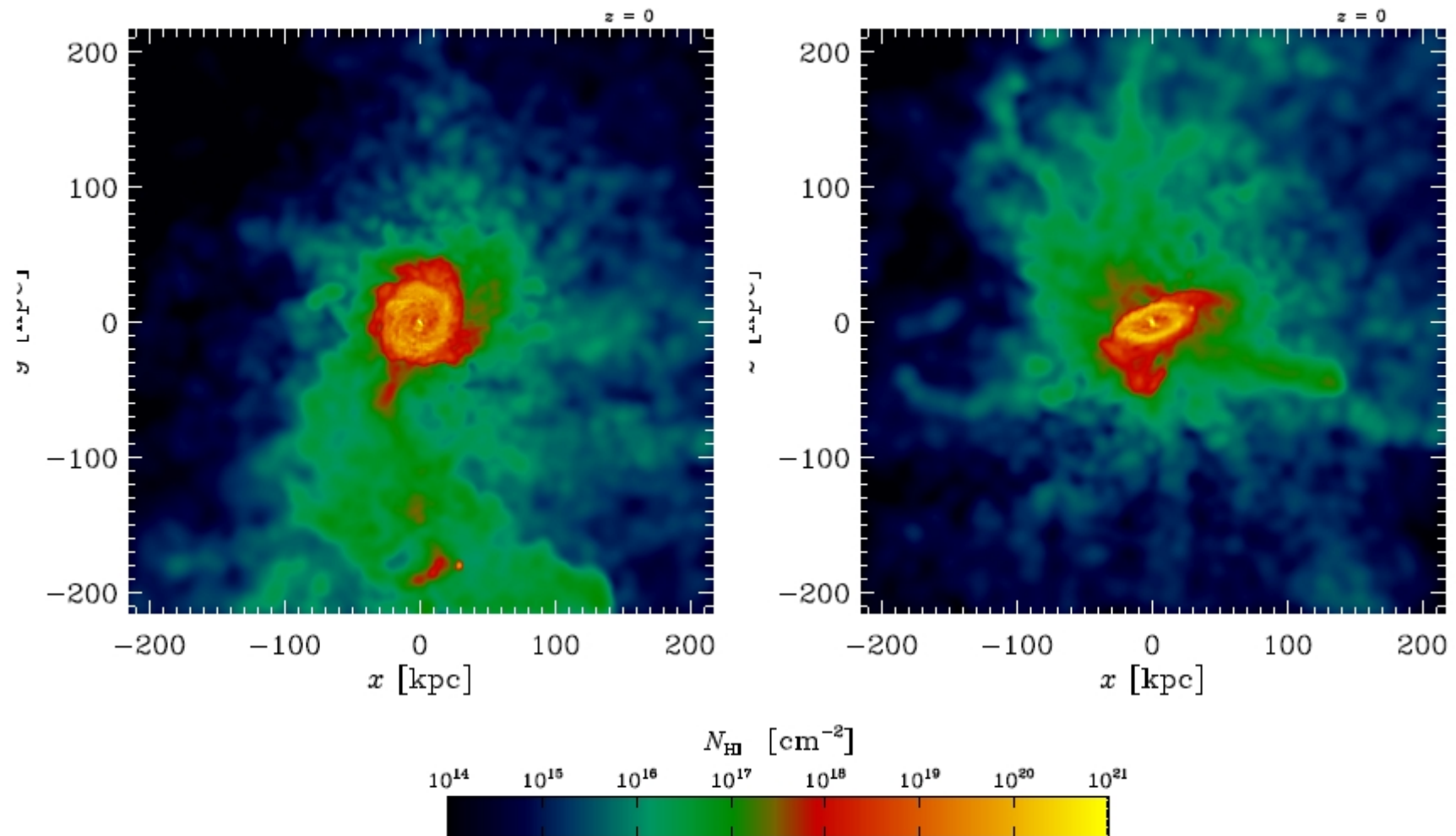
## The simulated Milky Way: gas distribution



(Nuza et al. 2013, in preparation)

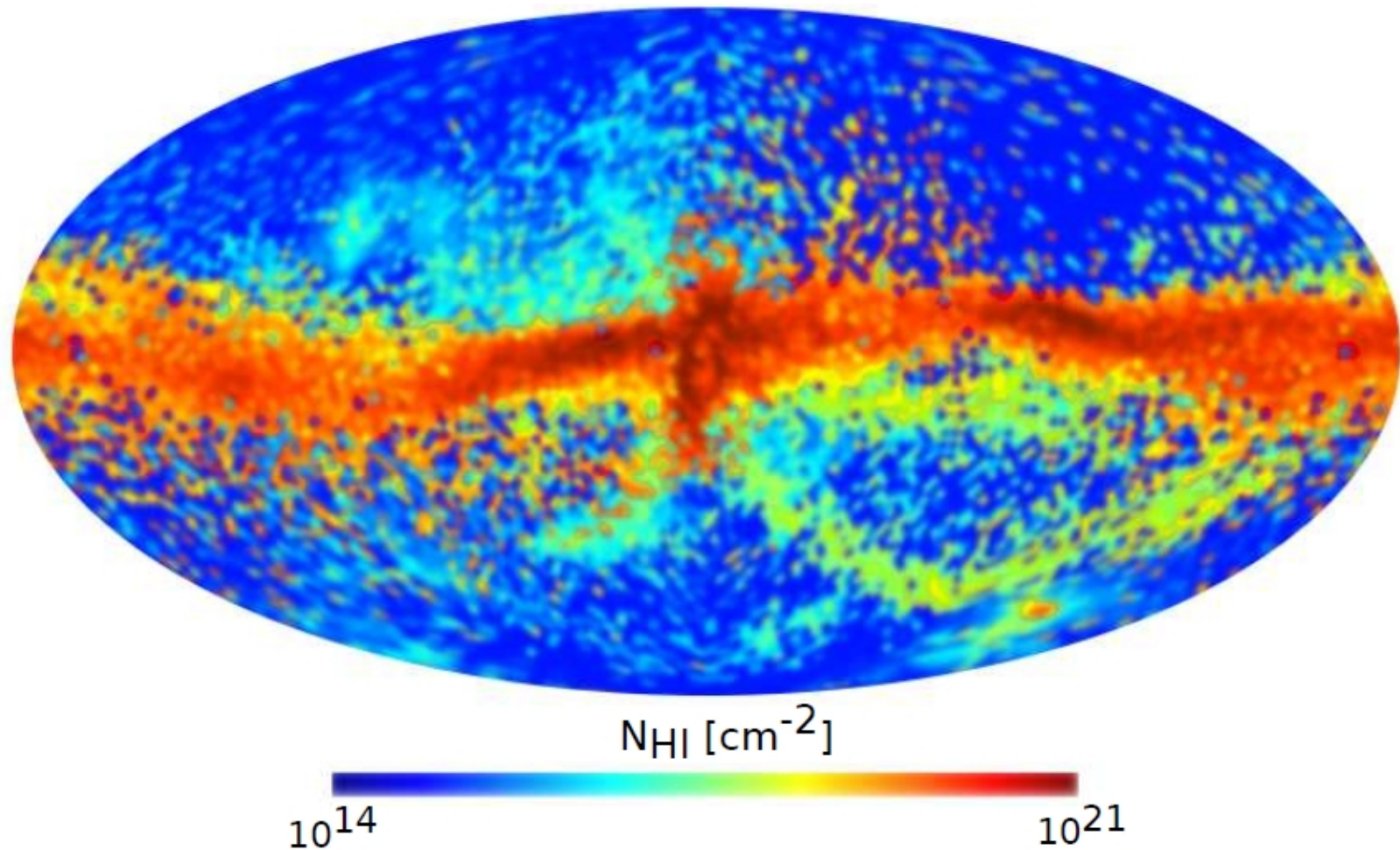
# Constrained simulations of the Local Group with CLUES

## The simulated Milky Way: HI distribution



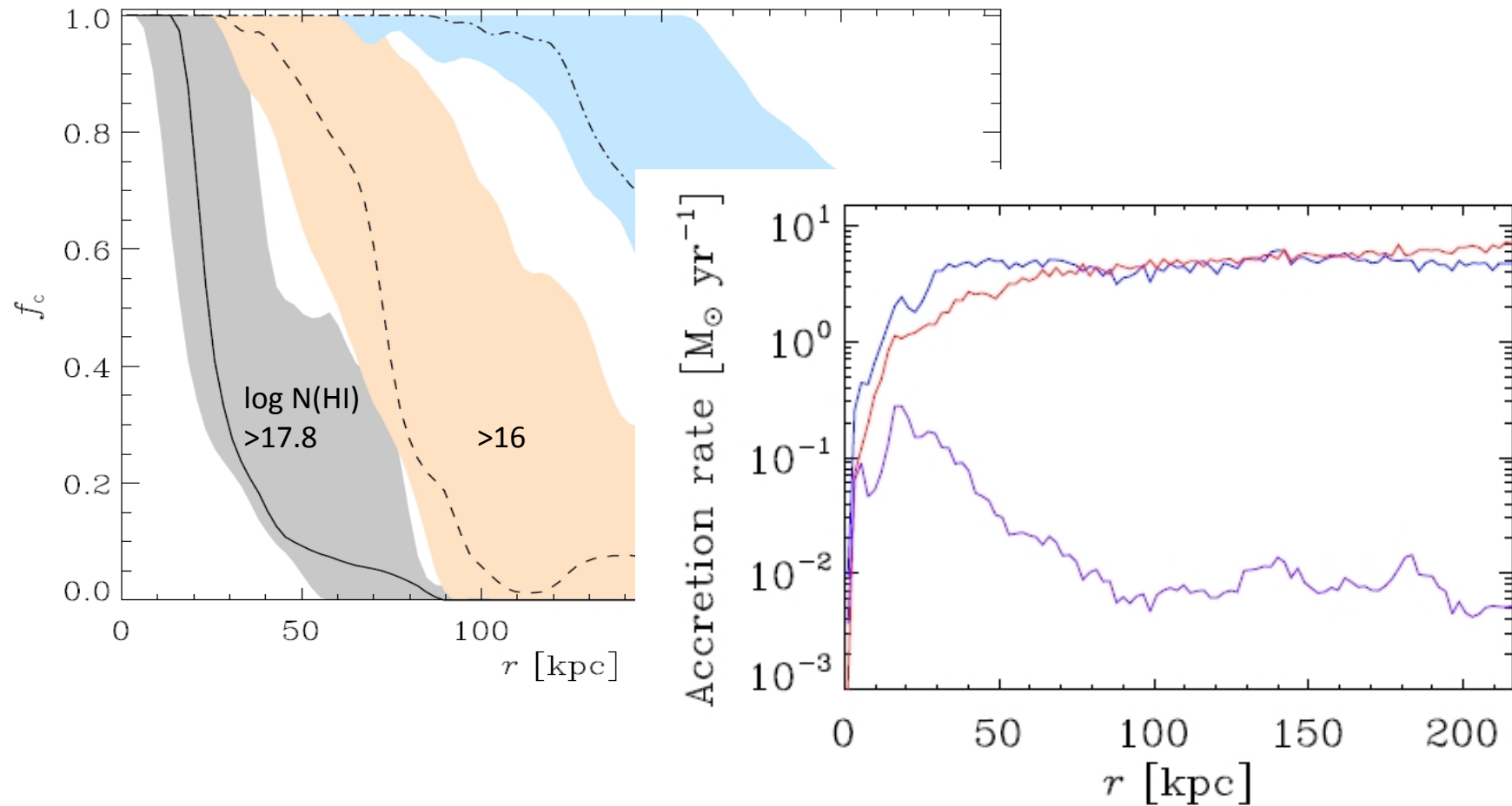
# Constrained simulations of the Local Group with CLUES

The simulated Milky Way: HVC sky



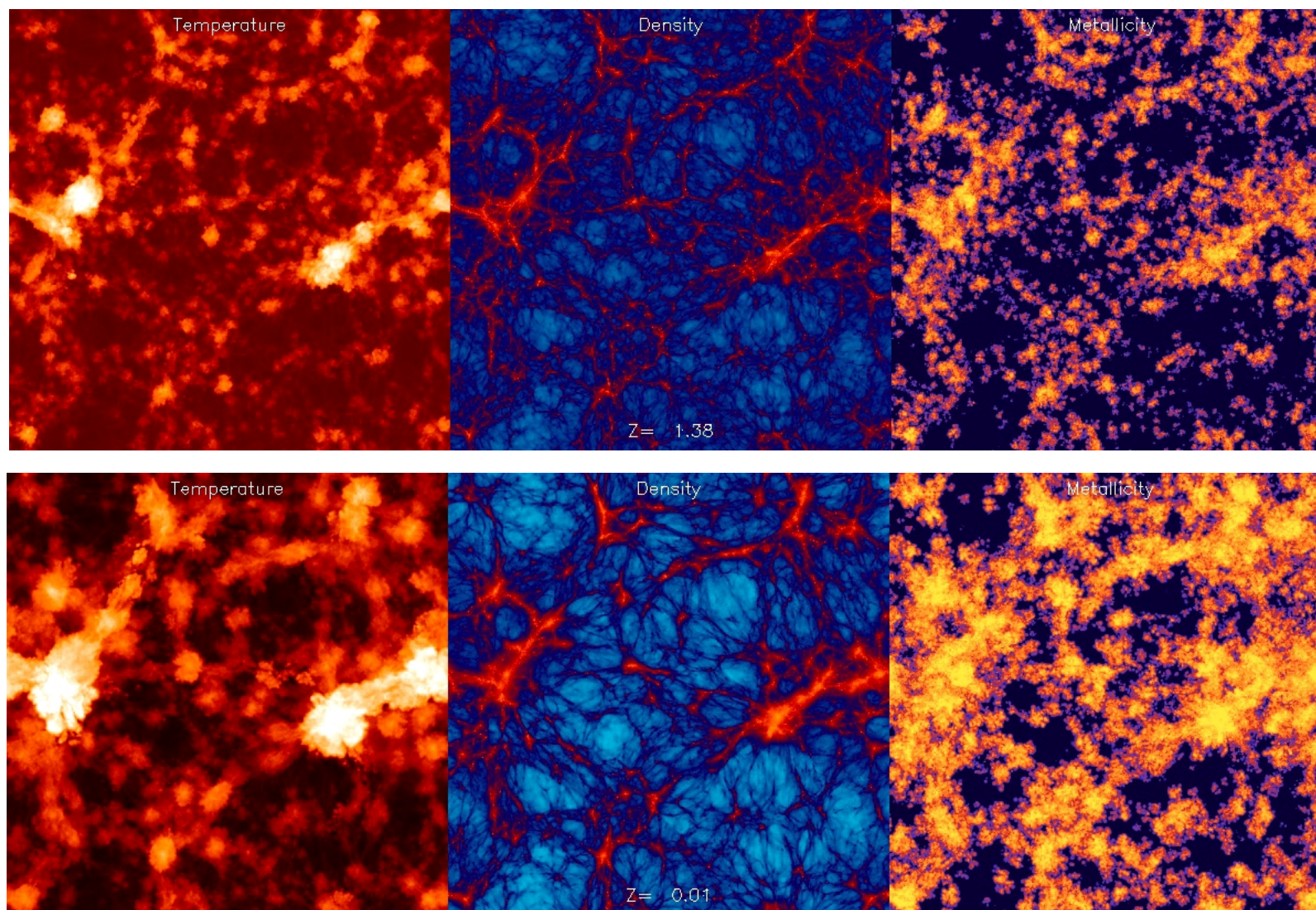
# Constrained simulations of the Local Group with CLUES

## The simulated Milky Way: HI radial distribution and HI gas accretion rates



(Nuza et al. 2013, in preparation)

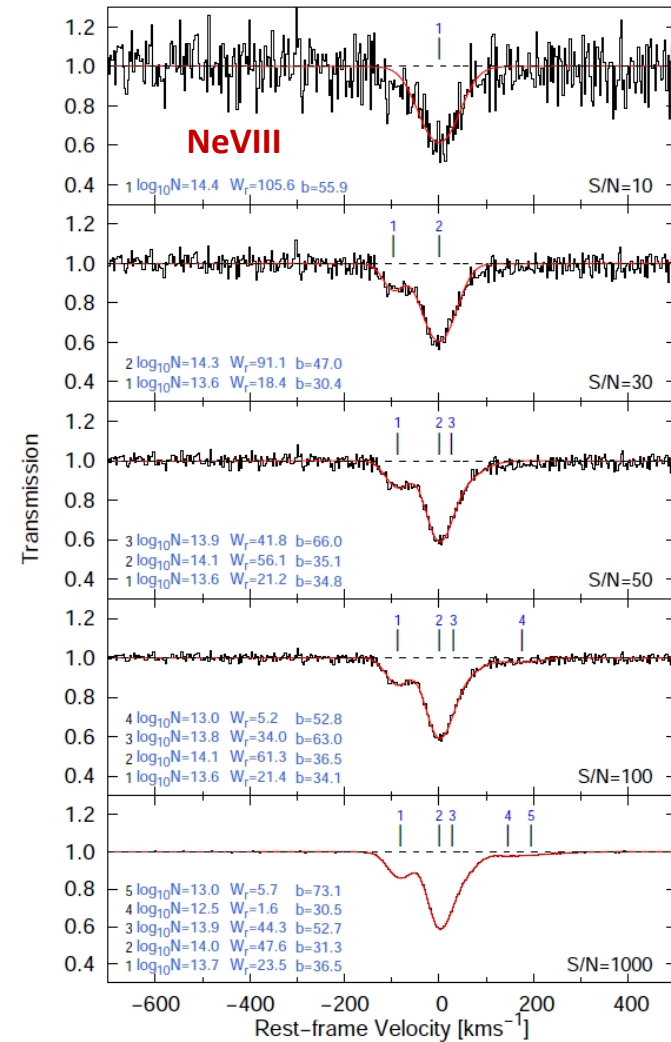
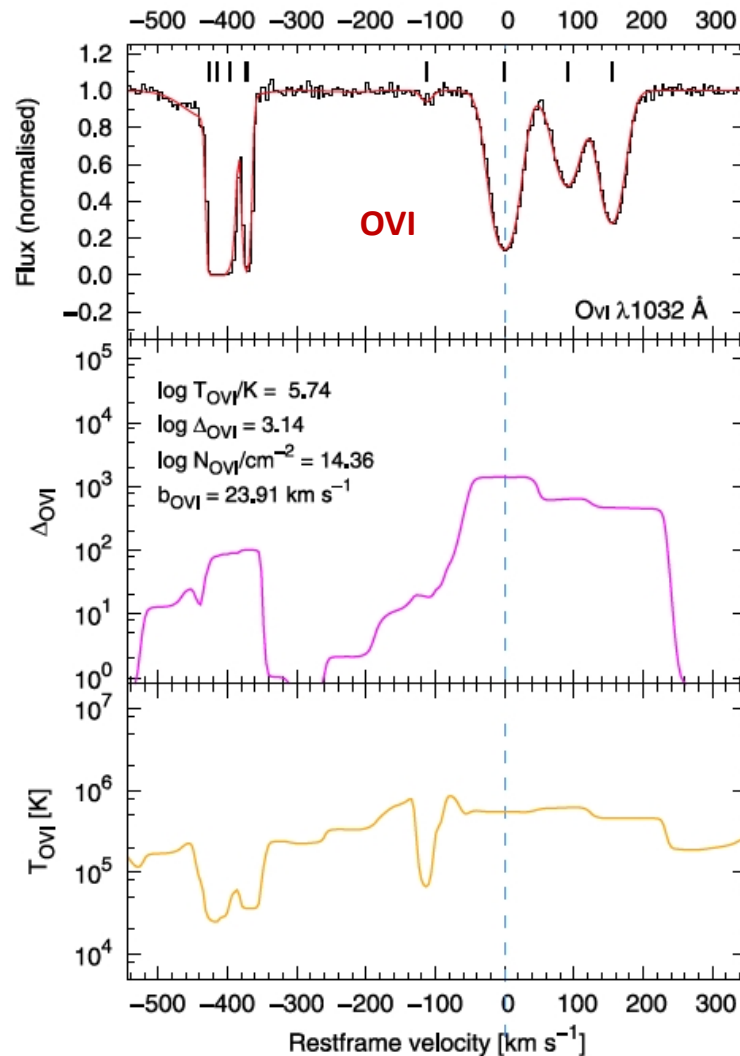
# OWLS simulations of the local warm-hot intergalactic medium



(Schaye et al. 2010; Craig Booth)

# OWLS simulations of the local warm-hot intergalactic medium

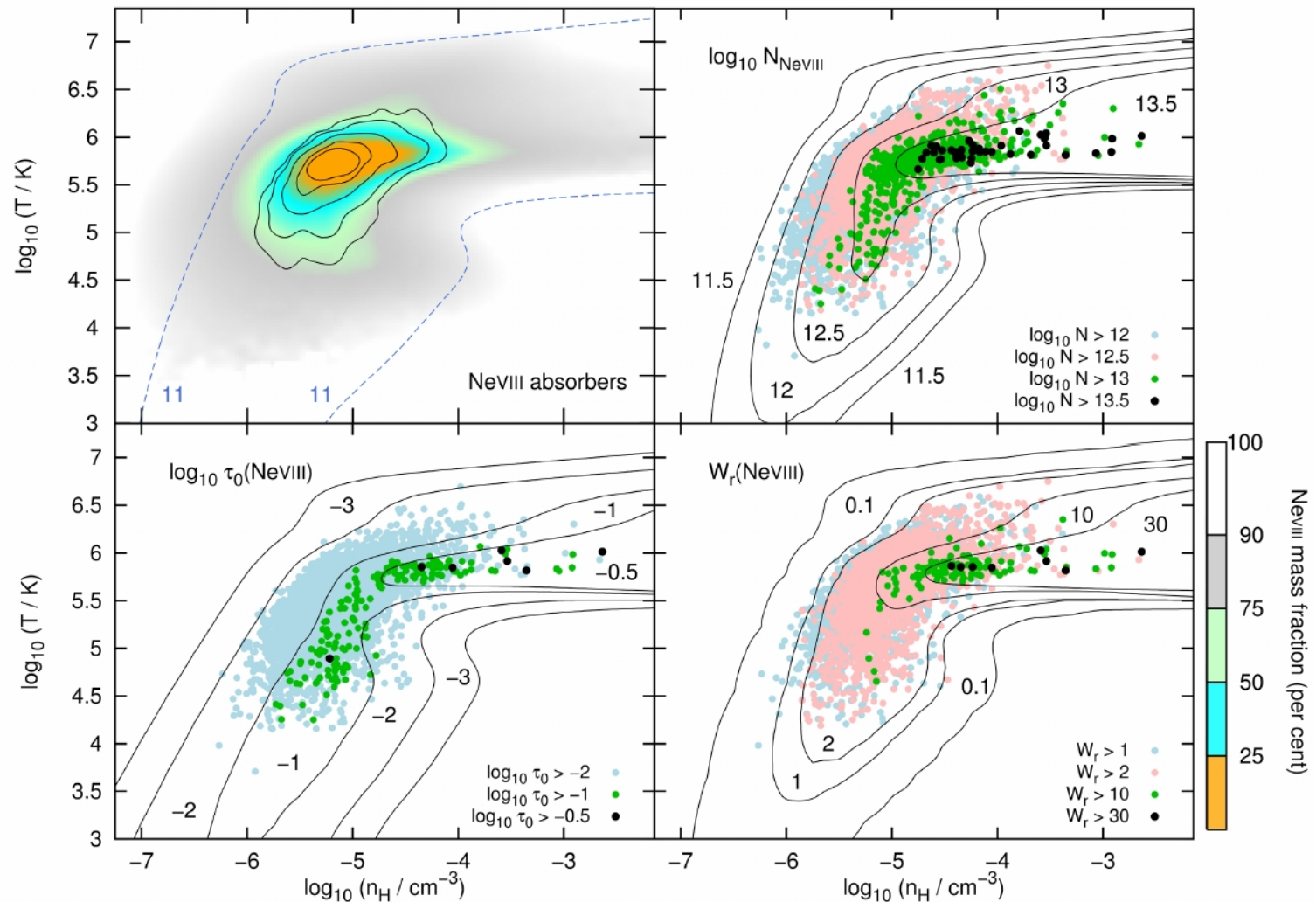
## OVI and NeVIII absorption in the WHIM



(Tepper-García et al. 2011; 2013)

# OWLS simulations of the local warm-hot intergalactic medium

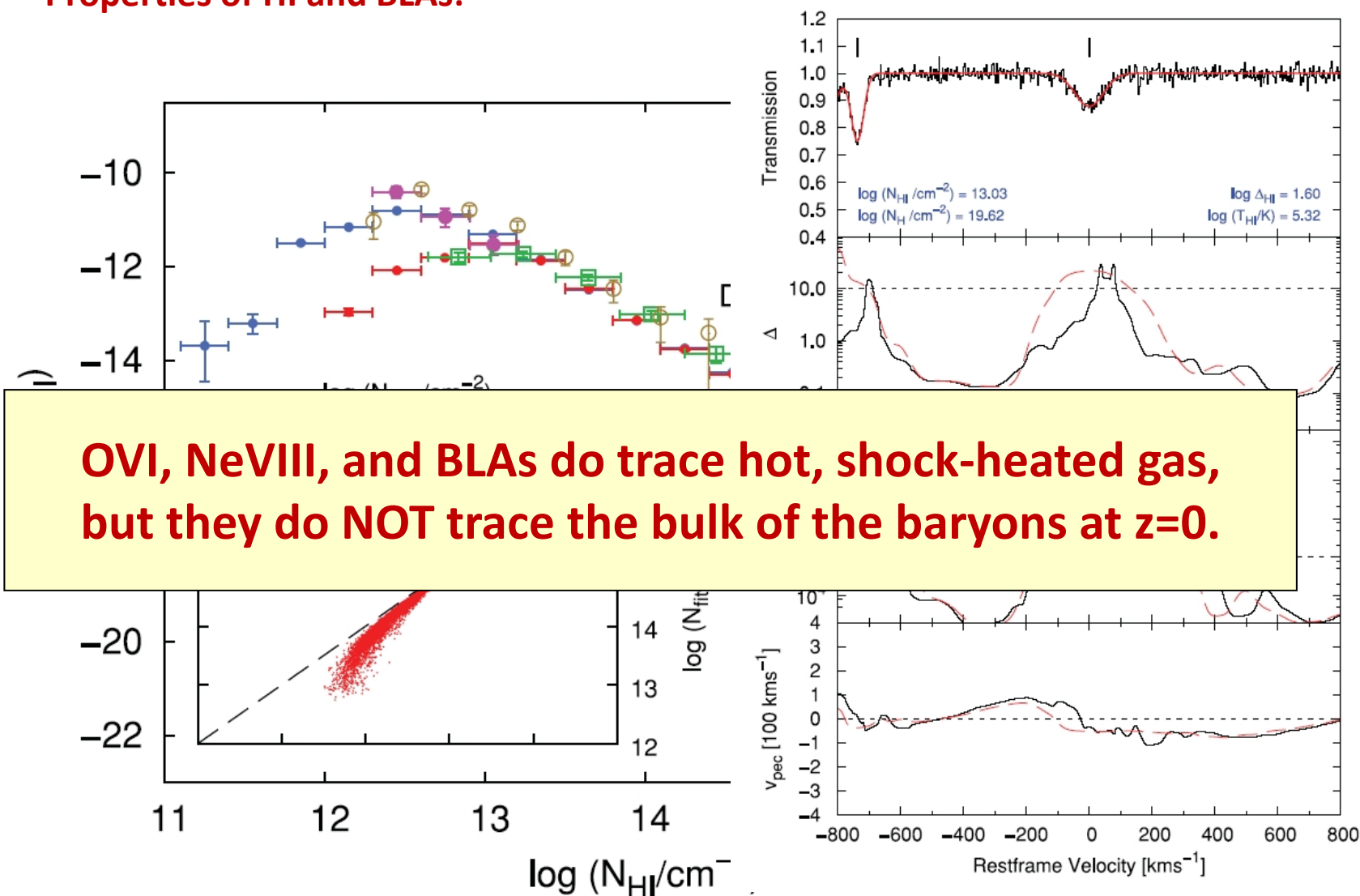
## Phase space of NeVIII absorbers at $z=0$



(Tepper-García et al. 2013)

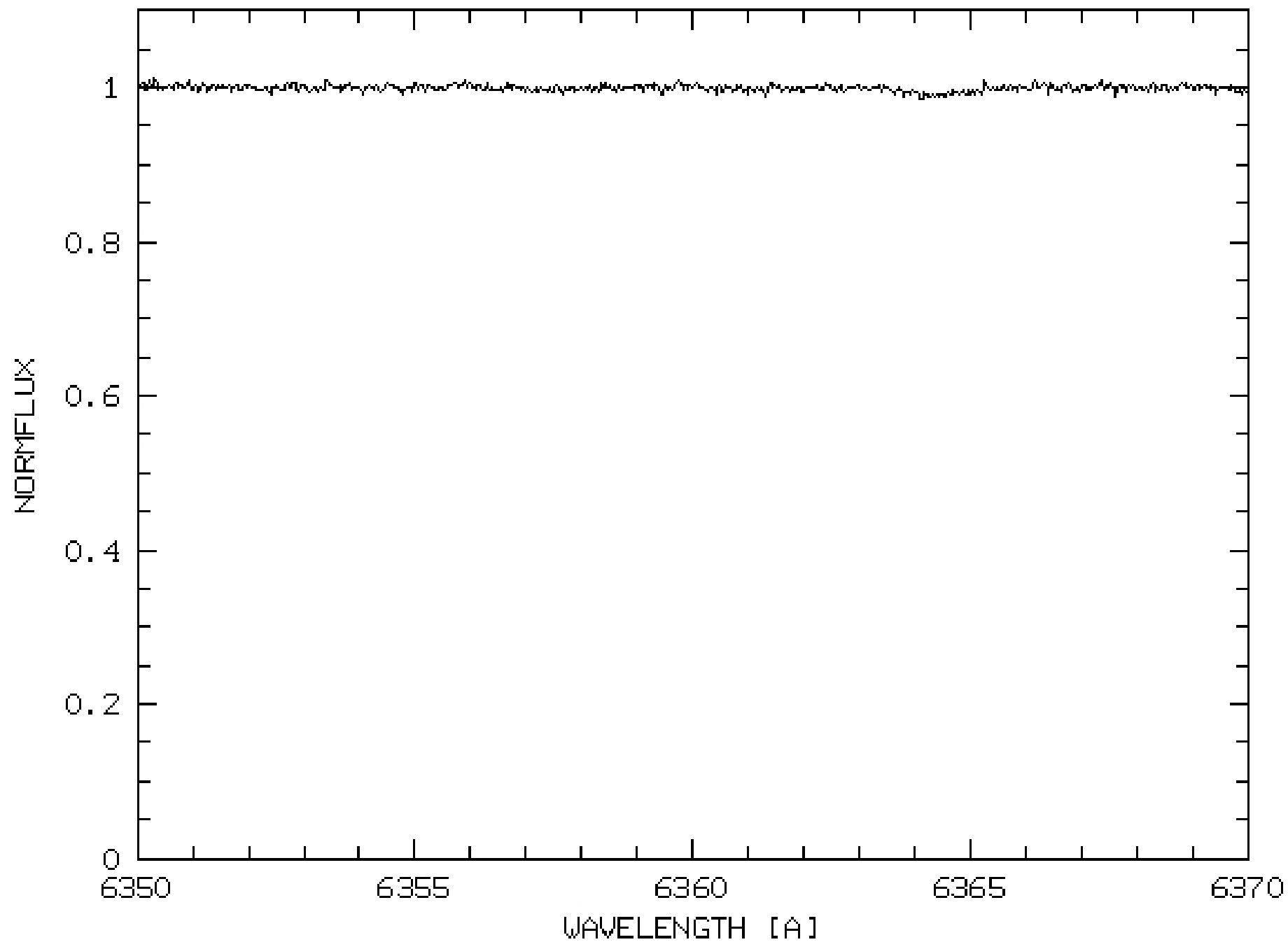
# OWLS simulations of the local warm-hot intergalactic medium

## Properties of HI and BLAs:



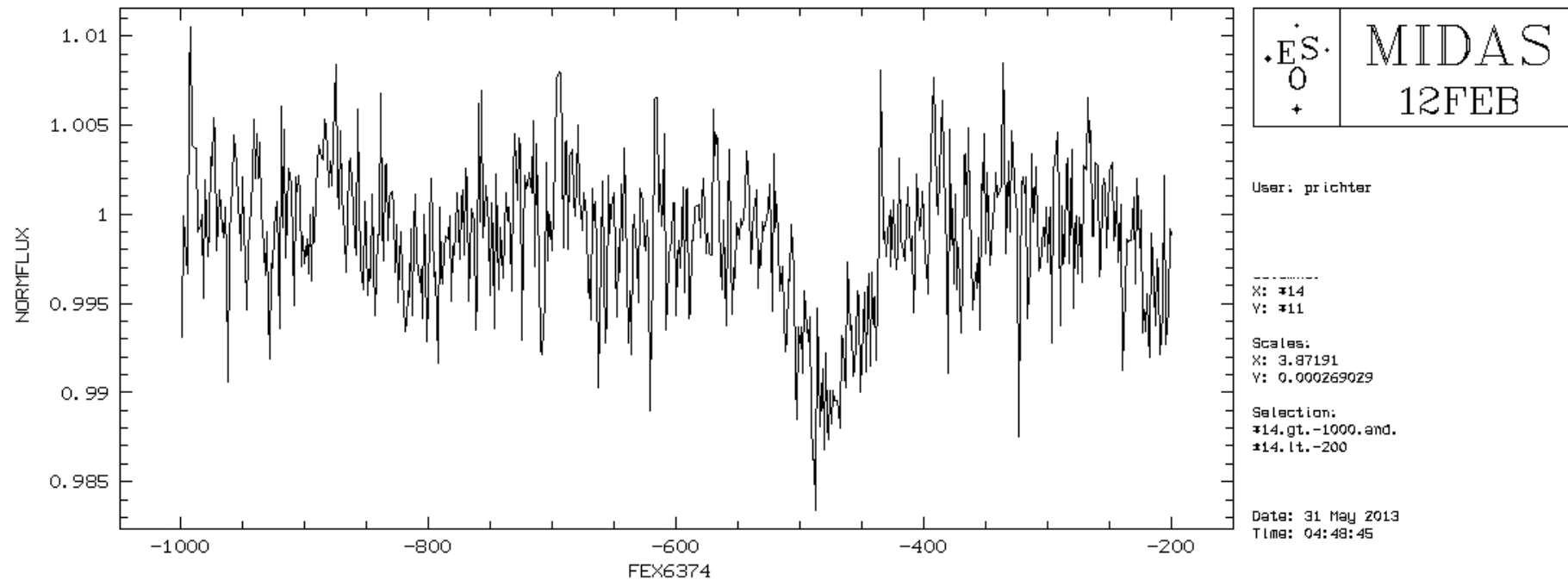
**OVI, NeVIII, and BLAs do trace hot, shock-heated gas, but they do NOT trace the bulk of the baryons at  $z=0$ .**

(Tepper-García et al. 2012)



# Optical [FeX] absorption in the Local Group ??

VLT/UVES survey of local [FeX] and [FeXIV] absorption:



- Local Group gas?
- Or just a unknown DIB ?
- **Work in progress ..... (UVES, SDSS)**

Thanks!

# MS and CLOUDY

