The CGM and the IGM in Galaxy Groups: Motivating Deep HI Absorption Studies

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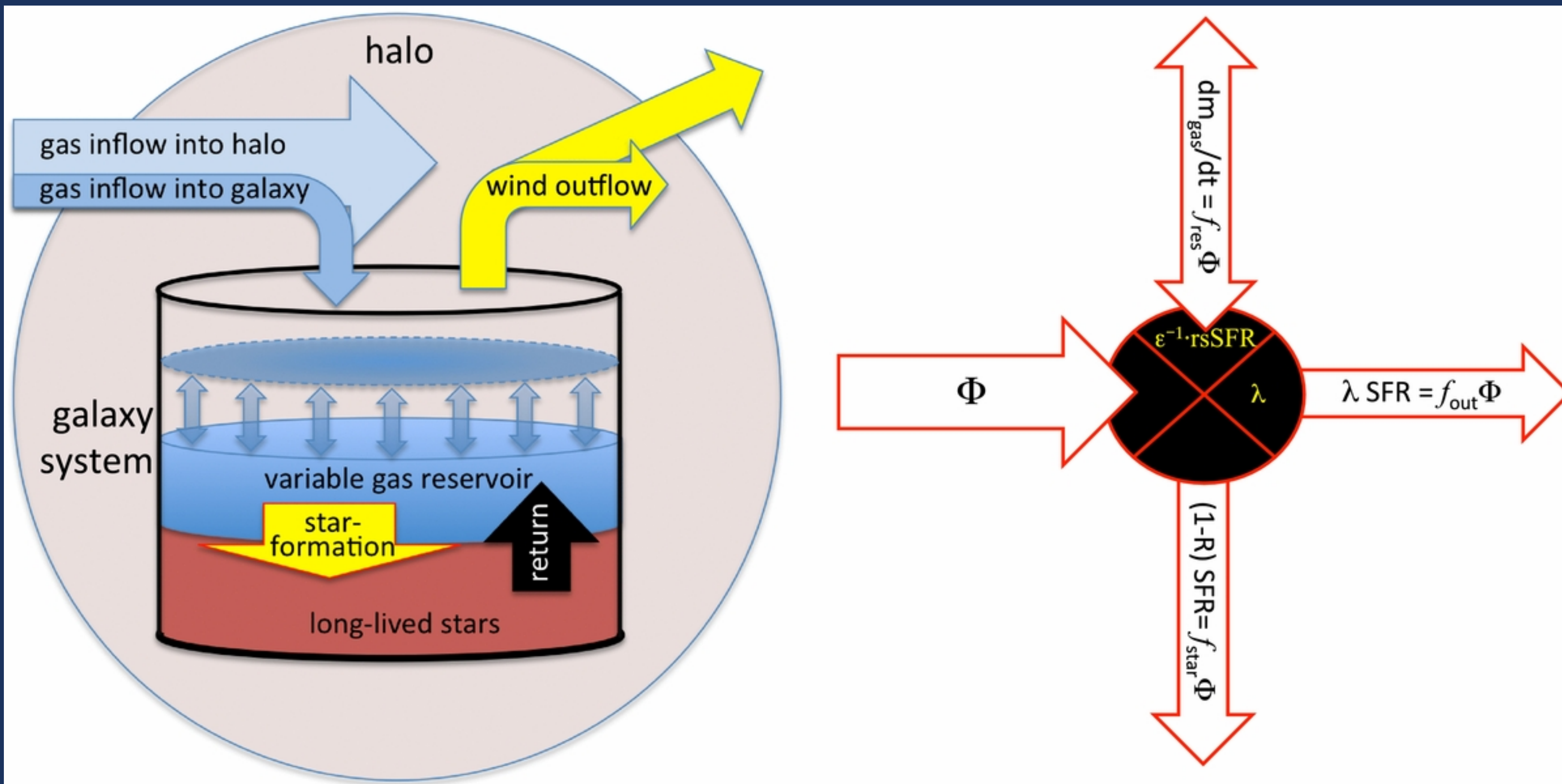
Overview

- What we know (and don’t know) about the CGM
- What we know (and don’t know) about the IGM in Groups
- The potential for new approaches with deep radio surveys

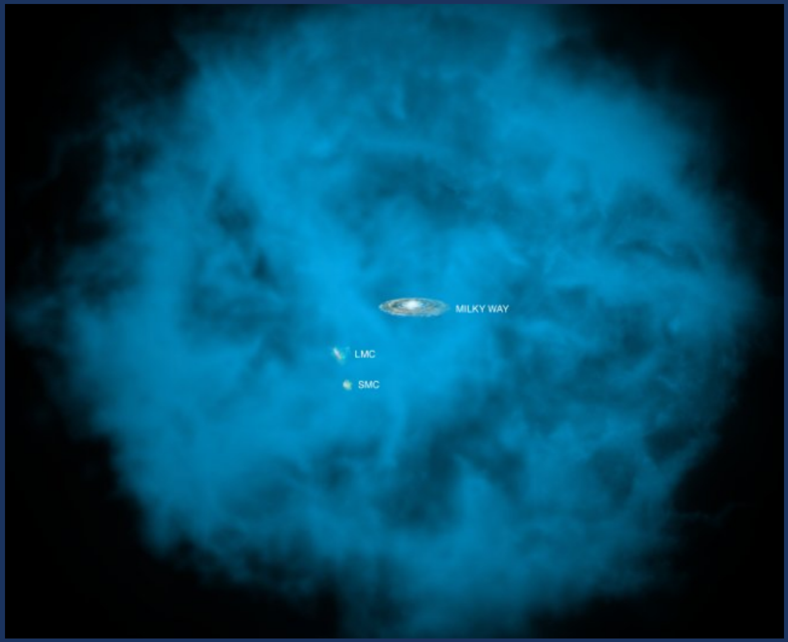
The CGM & Galaxy Evolution



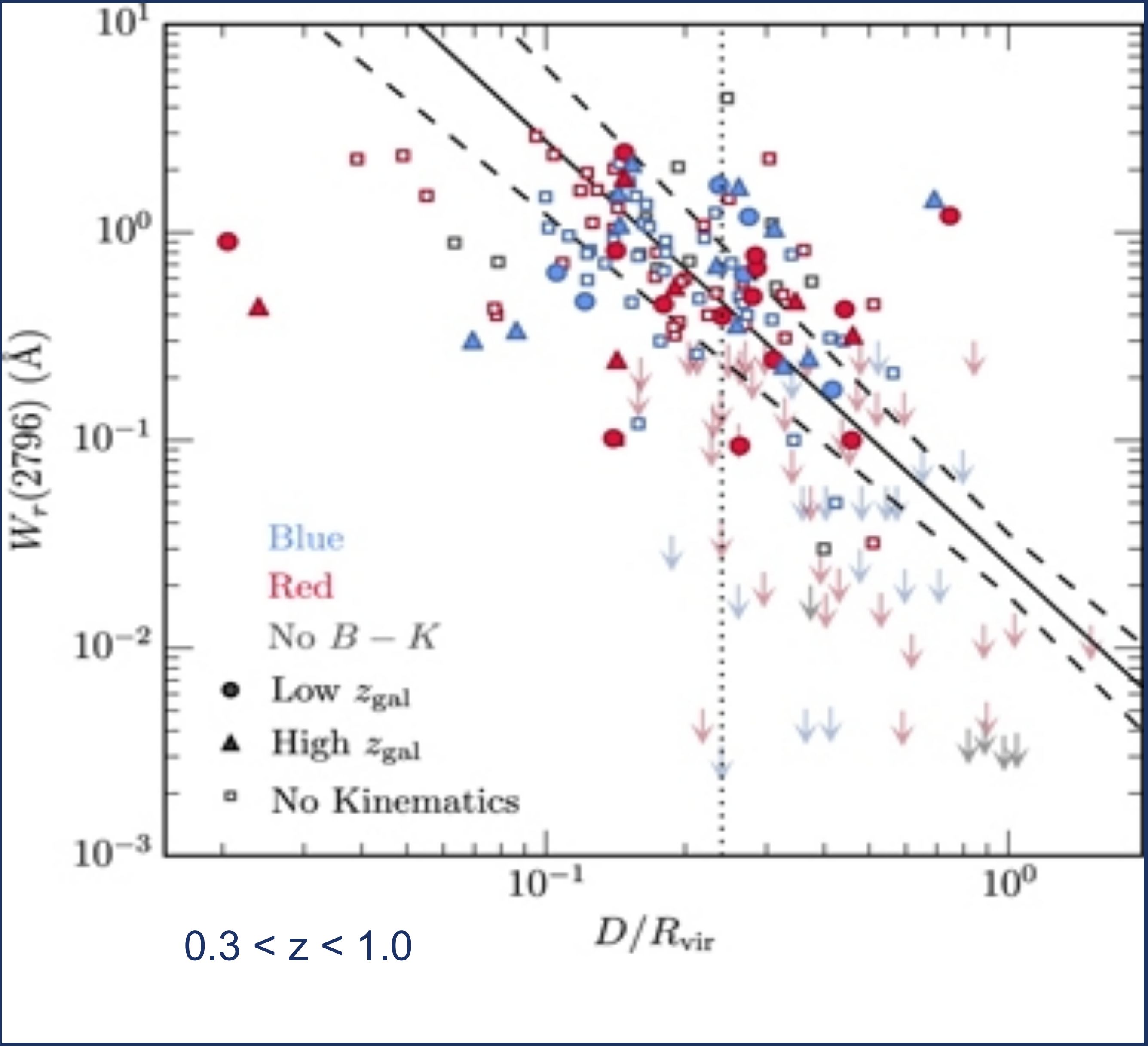
Lilly et al 2013

The Reservoir of Gas in the CGM

- Typically extends ~1 R_{vir}
- Usually probed via UV absorption lines (e.g. Nielsen et al [2016] – in 39 isolated galaxies, detect Mg II absorption out to 190 kpc; 13.3 < log N (Mg II) < 16.85)

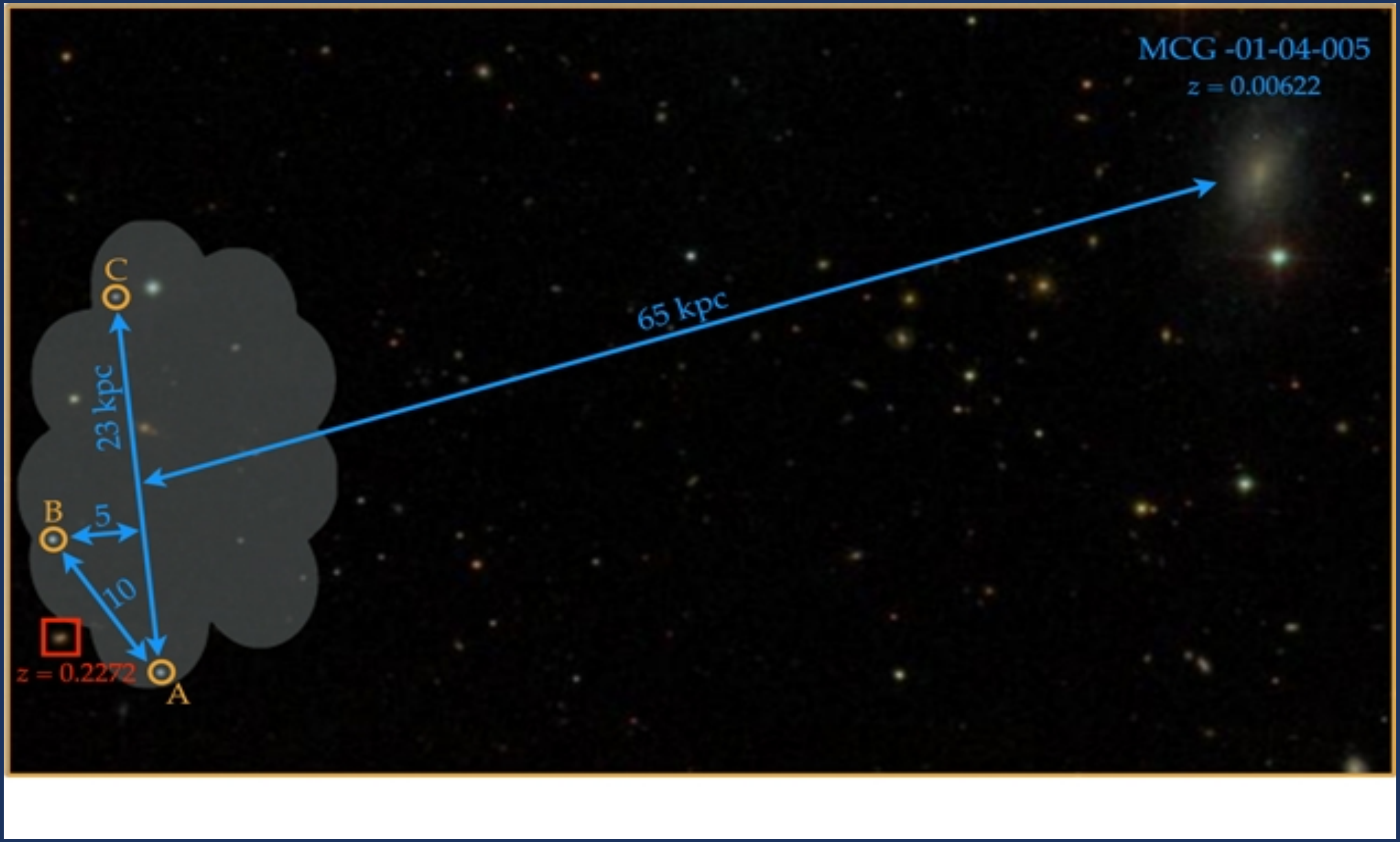


(Image courtesy of C. Tremonti)



Nielsen et al 2016

Davis et al. 2015 ApJ 810 92



Implies log N_{HI} ~ 15.5

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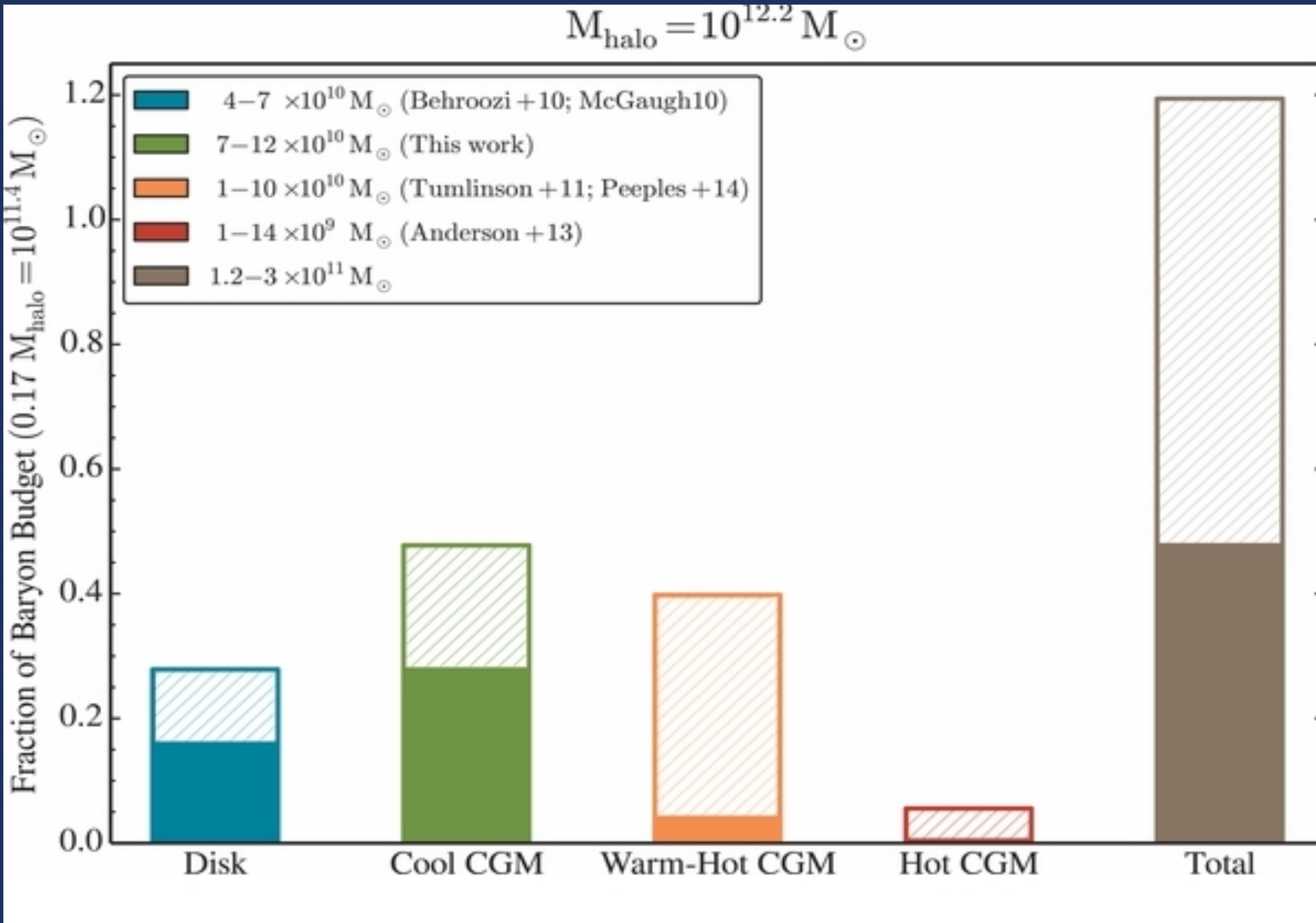
- Significant amount of gas – e.g. Lehner et al (2015) – CGM surrounding M31 to at least 50 kpc (HI only makes up ~3%)
- Gas mass in CGM comparable to gas mass in galaxy
- Can be both the reservoir for further SF and/or the repository of feedback from star formation.



Werk et al. 2014 ApJ 792 8

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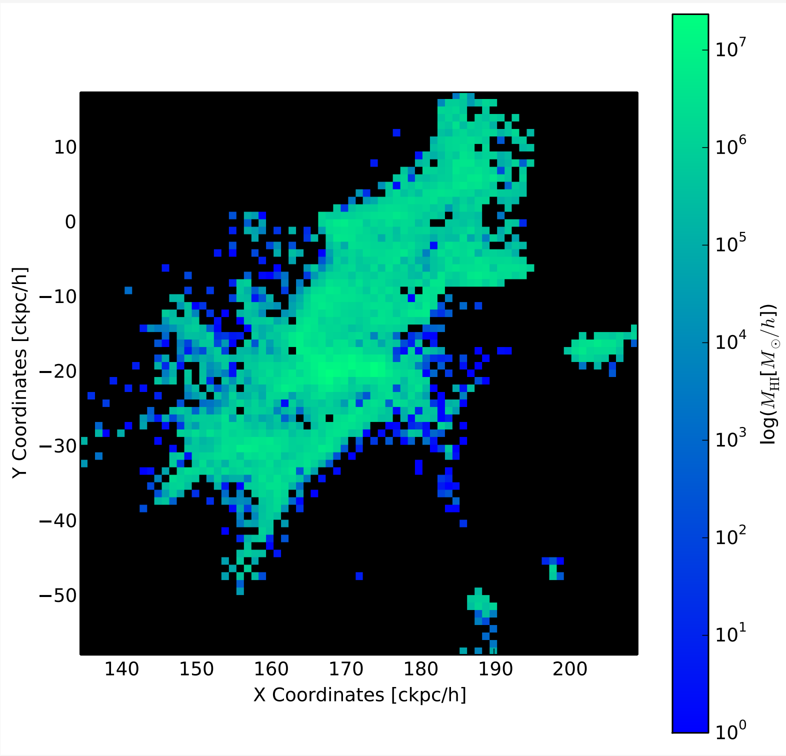
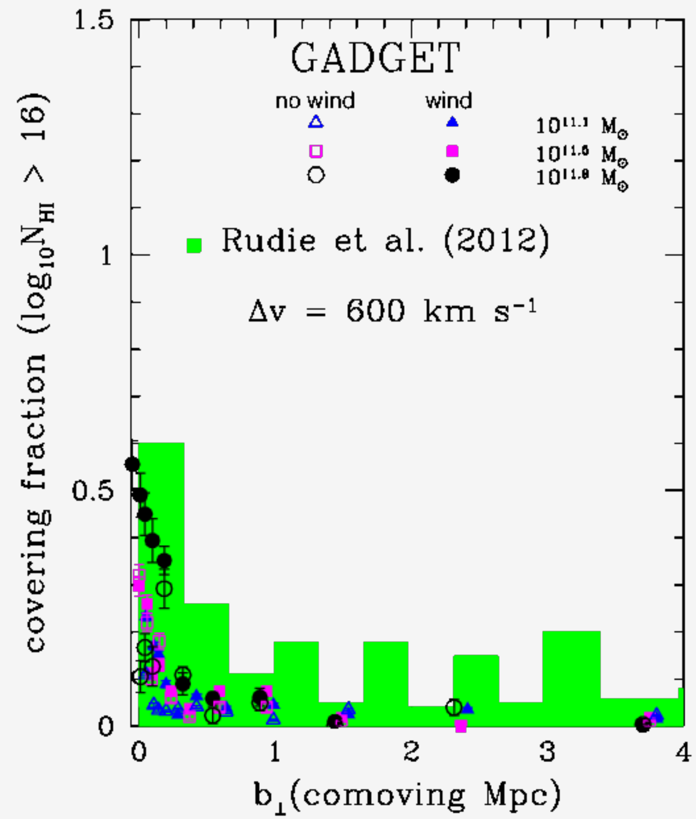
- Implied/derived HI column densities of 14 < log N(HI) < 19

illustris – TNG simulation



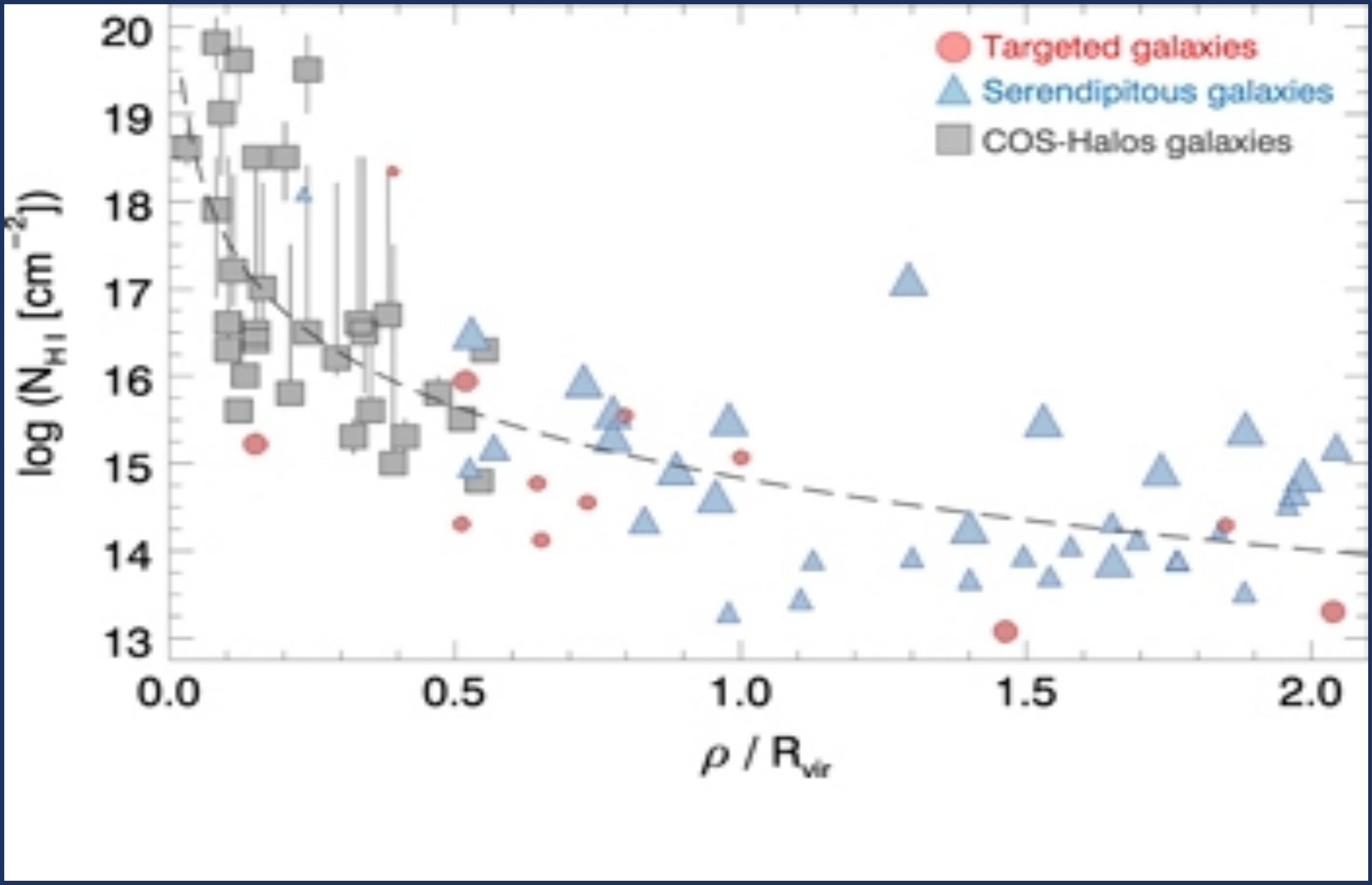


Courtesy A. Kundert

Meiksin 2016, Bolton & Tittley 2015

HI mass per 1 kpc^2 pixel for an L^* halo,

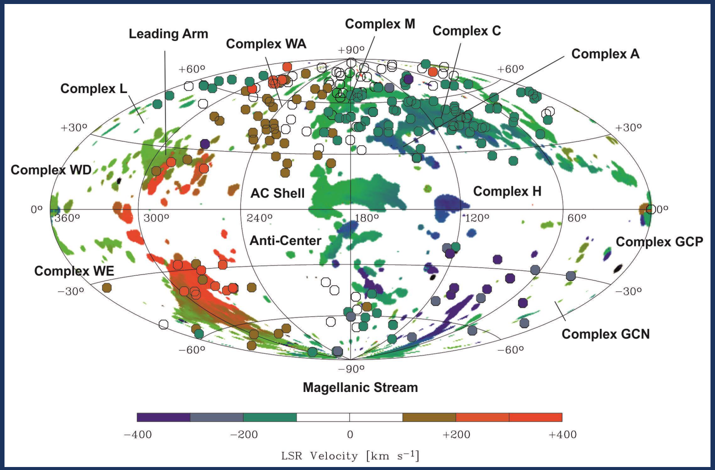
Derived N_{HI} from Mg II absorption line studies



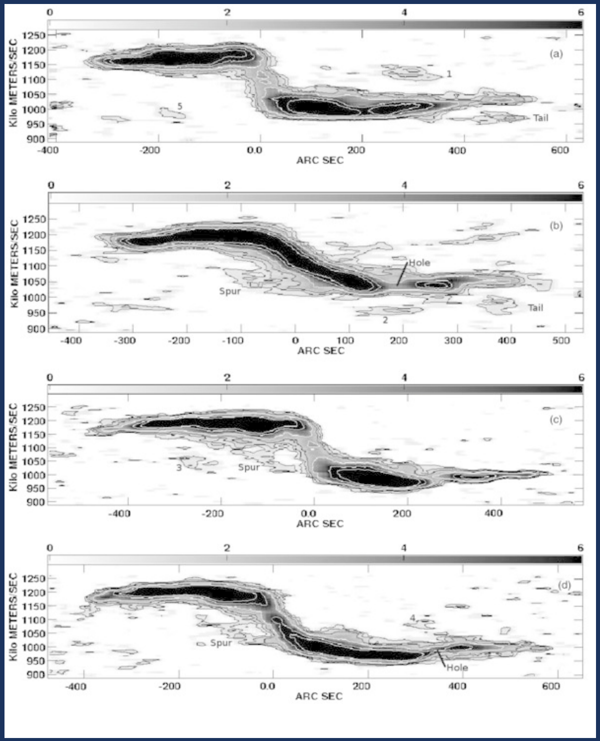
Keeney et al. 2017, Werk et al 2014

Direct detection of the neutral CGM?

- Some of the high velocity clouds?



MWG - Richter 2016

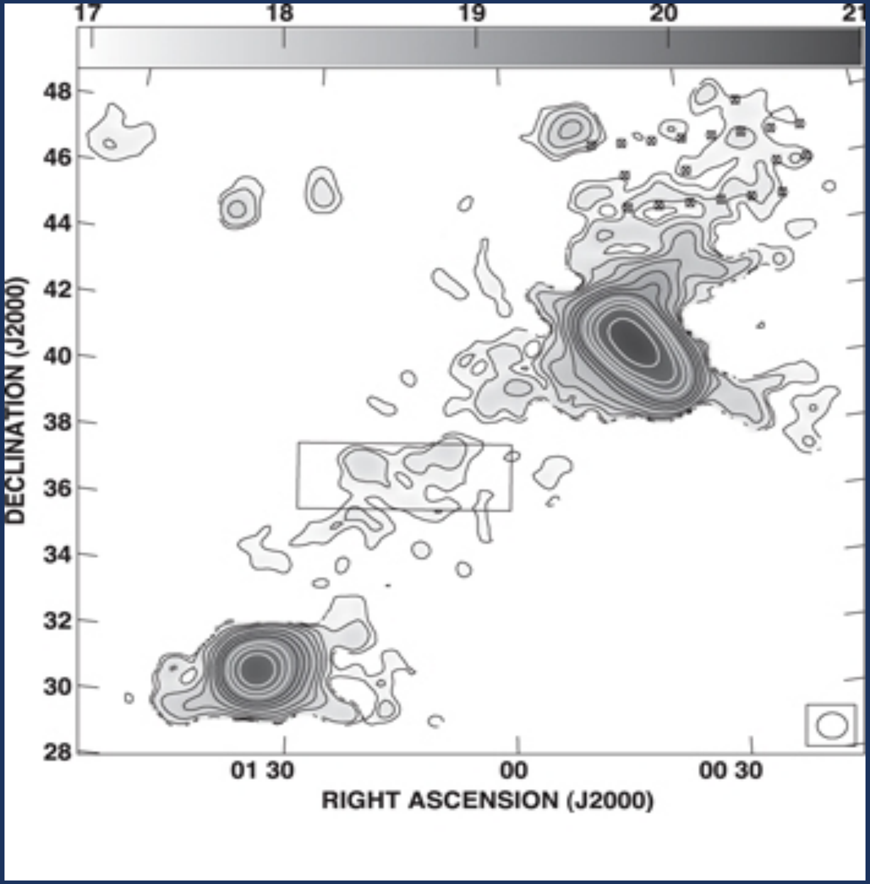


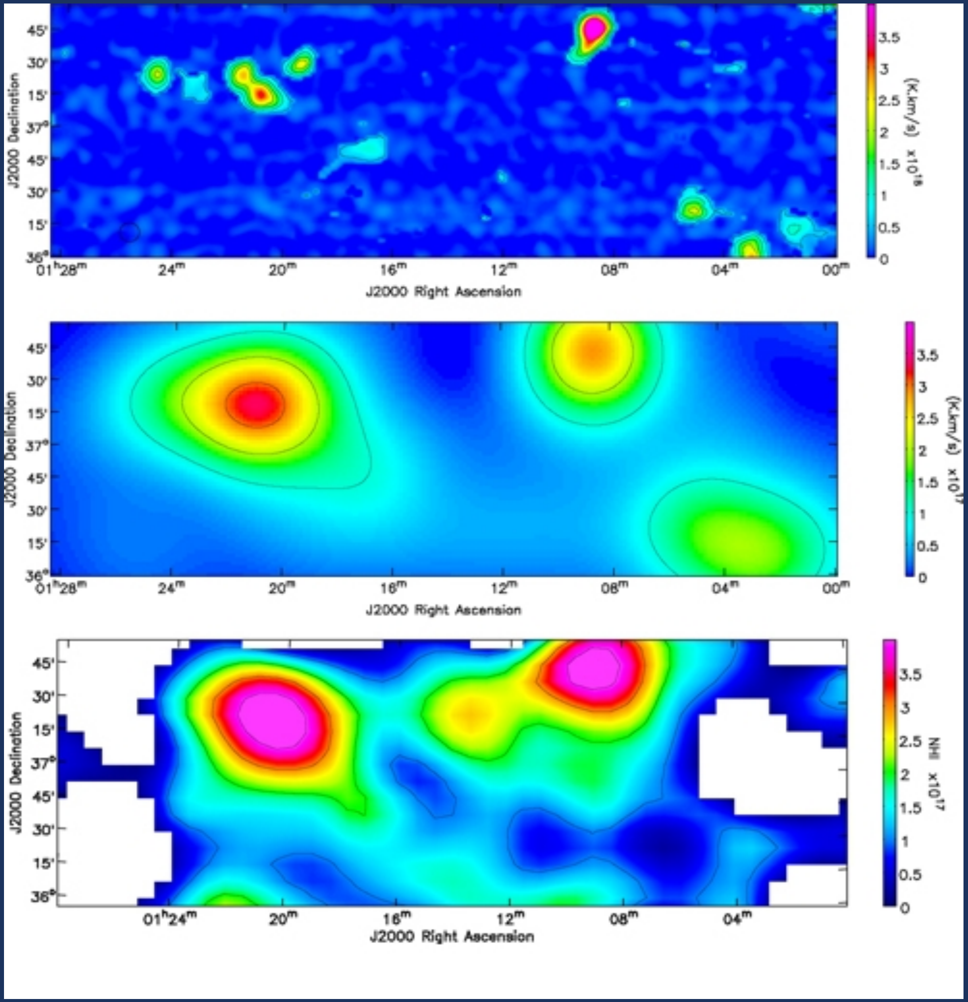
NGC 2997 – Hess et al

(Also see recent work by Ashley et al on a sample of nearby dwarf galaxies)

Direct detection of the neutral CGM?

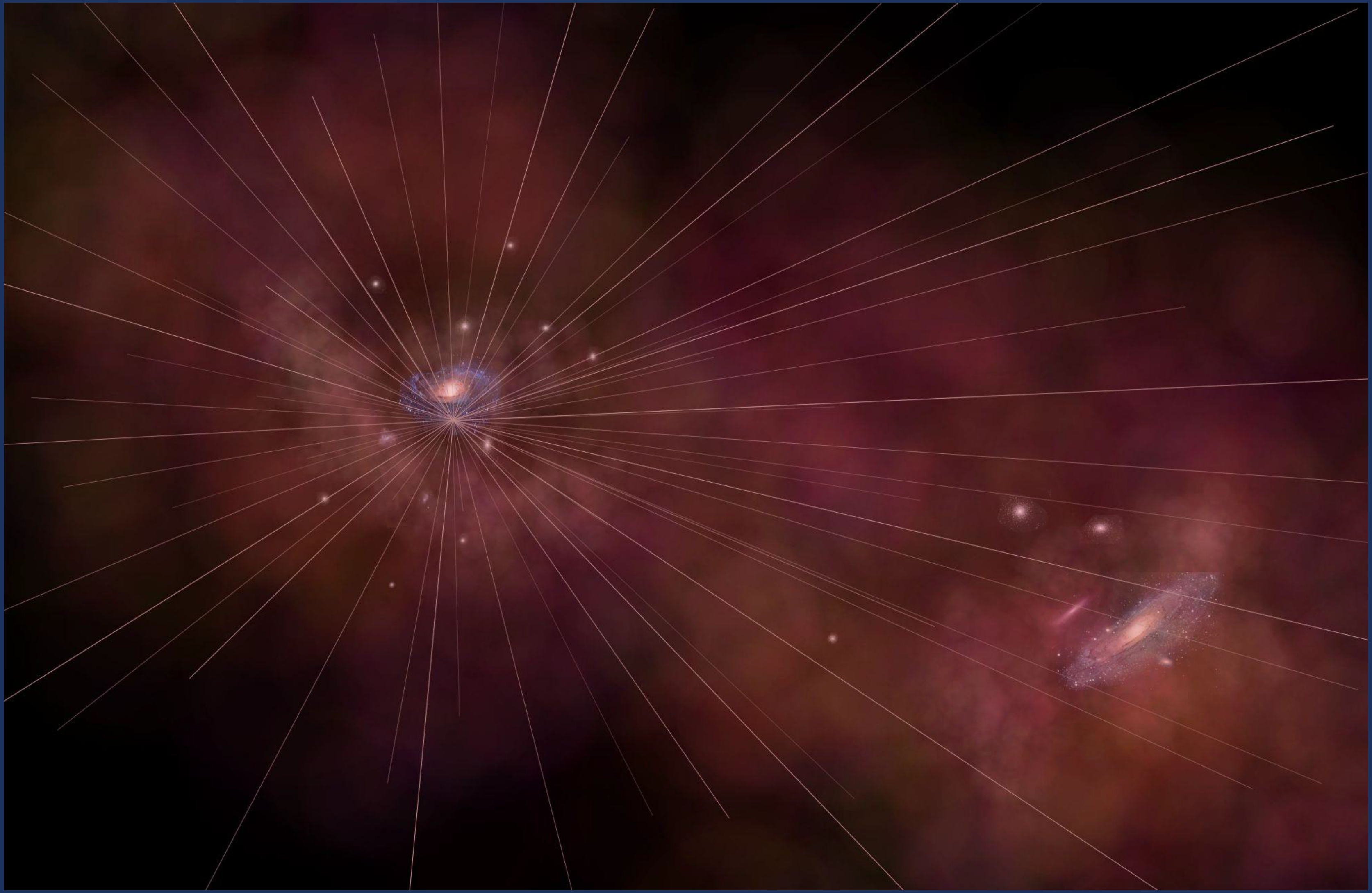
- M31/M33





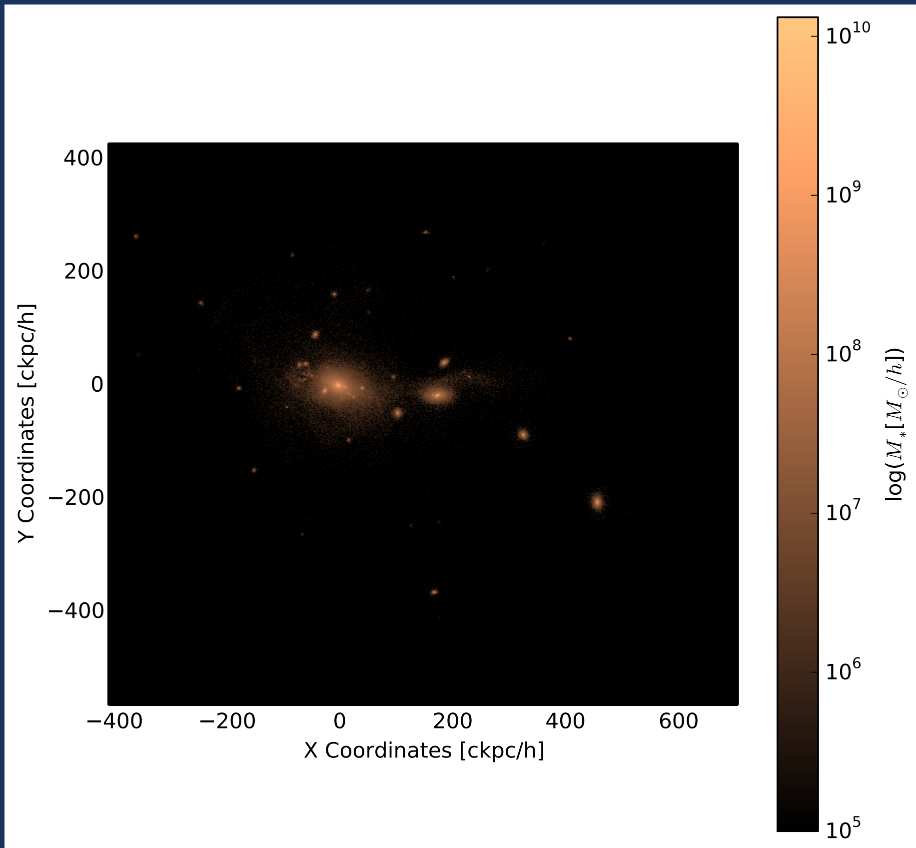
Wolfe et al. 2016

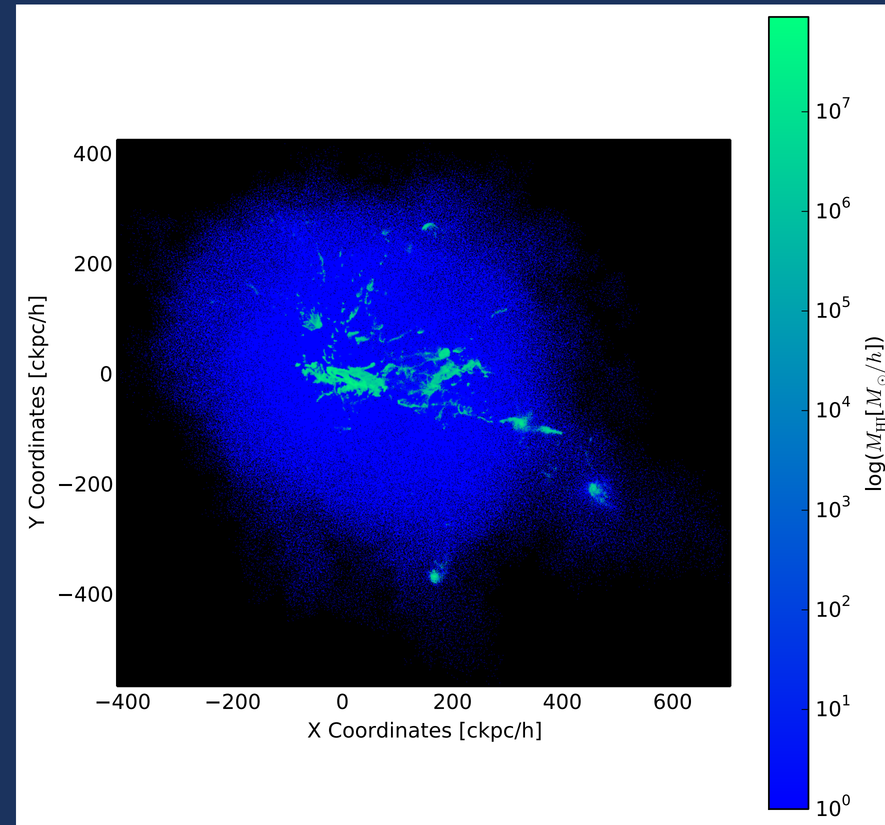
The CGM in the Local Group



Richter 2016

The Gas Content of Galaxy Groups





Kundert, EMW, Hess+

Tracing the IGM in Galaxy Groups

NGC 2563 – dynamically evolved group

64 confirmed members
R_{vir} = 1.15 Mpc
σ = 364 km s^{-1}

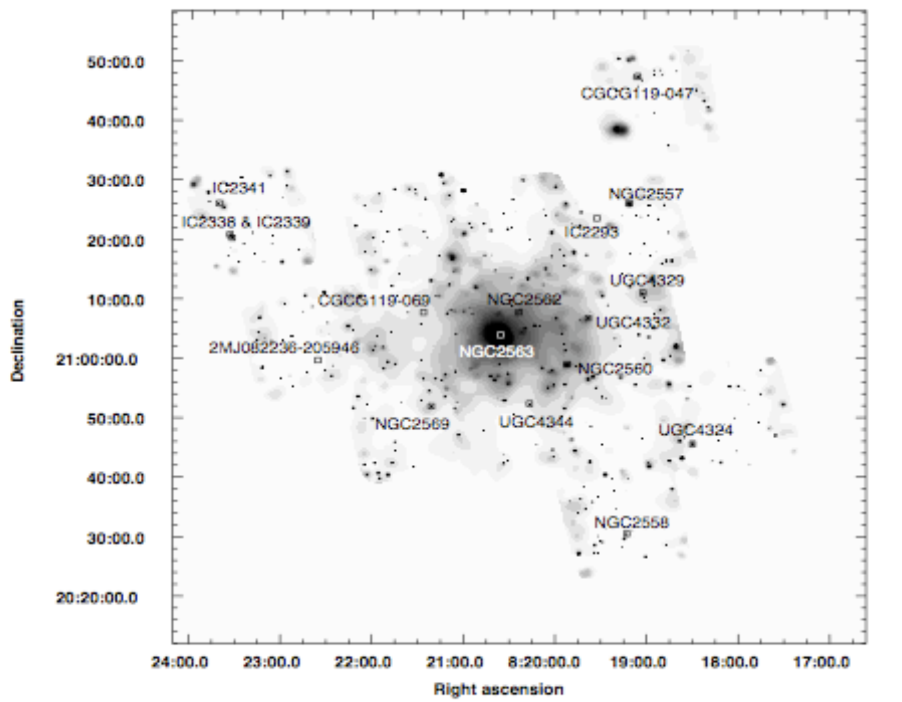


Fig. 1.— Soft X-ray (0.5 – 2.0keV) image of the NGC2563 group from 14 Chandra ACIS-I pointings. Color is plotted on a log scale. All X-ray detected group members are marked with squares. Note that some of the detected group galaxies are smeared out in the smoothing process and therefore are difficult to see in the image.

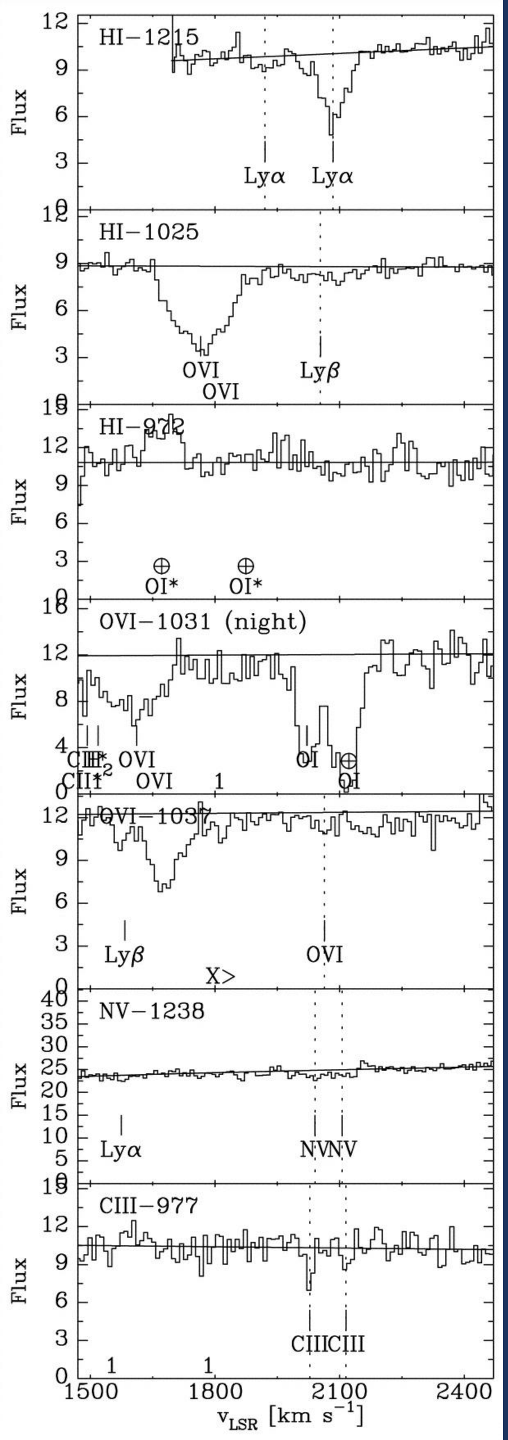
Rasmussen et al. 2011

17 x-ray detections

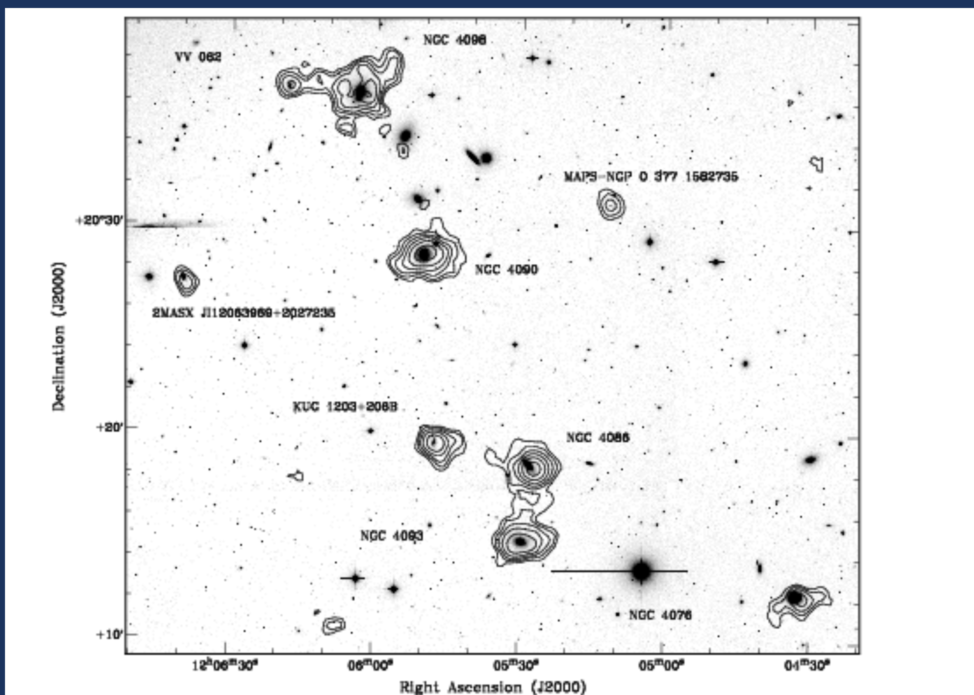
Quasar absorption lines can trace the IGM, but with only single sightlines.

- Mrk 817 sightline through GH 144, ∼ 370 kpc from nearest galaxy
- assuming photo-ionization from background radiation, metallicity, radiation field, filling factor
- $n > 10^{-4}\ cm^{-3}$ but size scale < 22 kpc

Pisano et al. 2003

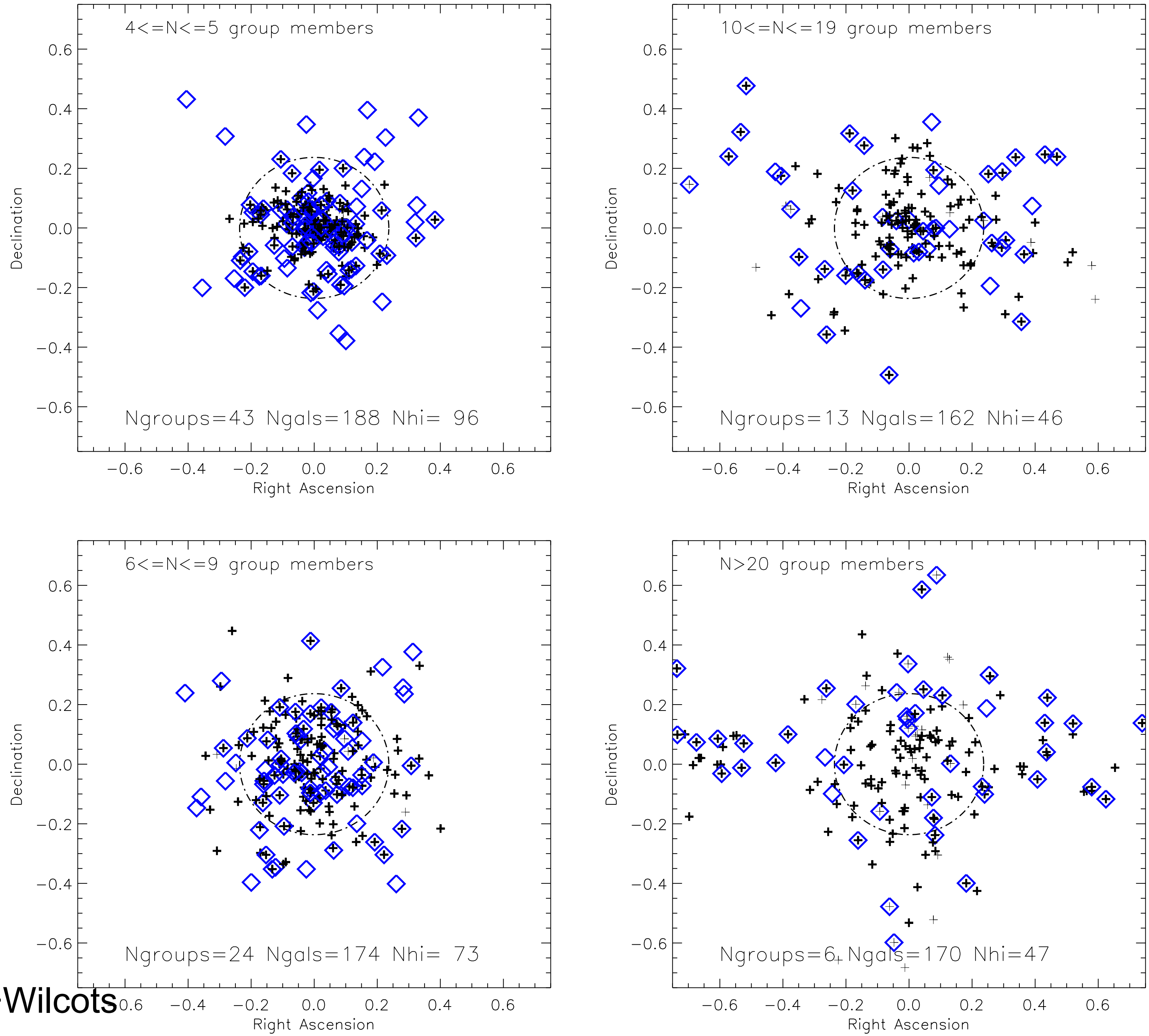


What We Know About HI in Nearby Galaxy Groups



- Interaction rate in spiral-dominated groups is high.
- A number of cases in which galaxies reside in a common HI envelope
- HI detected galaxies in evolved groups reside well outside the X-ray extent
- Spiral dominated/HI rich → elliptical dominated/X-ray rich

Freeland et al. 2009 (similar results from Kern+2008, Kilborn+2009, Pisano+2011, new results from ASKAP)

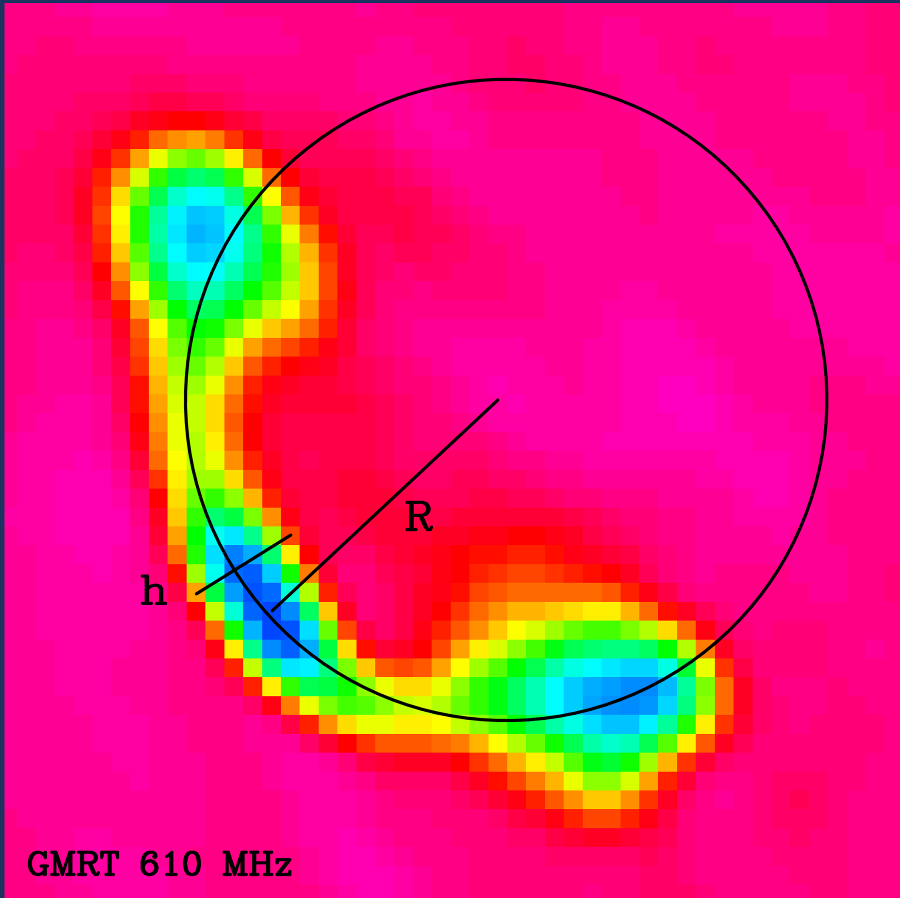


Hess+Wilcots

If the bending is caused by ram pressure then deriving the density of the IGM depends on:

- The radius of curvature of the jet (R)
- The thickness of the jet, h
- Velocity of the jet, v_{jet}
- Velocity of the galaxy relative to the environment, v_{gal}

$$\frac{\rho_{\mathrm{IGM}} v_{gal}^2}{h} = \frac{\rho_{\mathrm{jet}} v_{\mathrm{jet}}^2}{R}$$



Freeland et al 2008

Using the improved sensitivity of radio telescopes to trace both the CGM and IGrM

Faraday Rotation

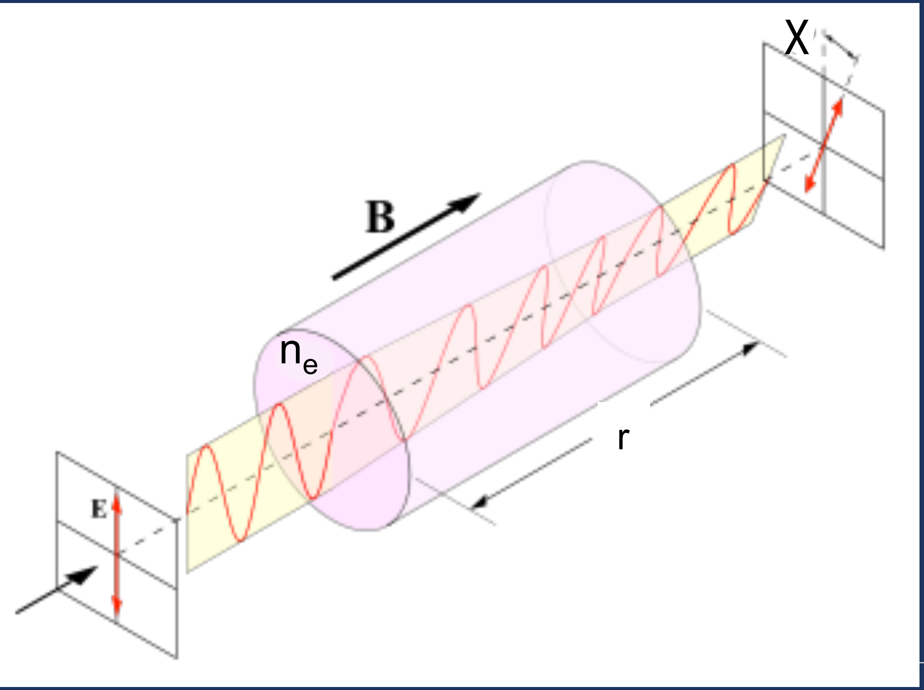
$$\phi(r) = 0.81 \int_{there}^{here} n_e \vec{B} \bullet d\vec{r}$$

(rad m^{-2})

n_e = cm^{-3}, **B**=μG, **dr**=parsec

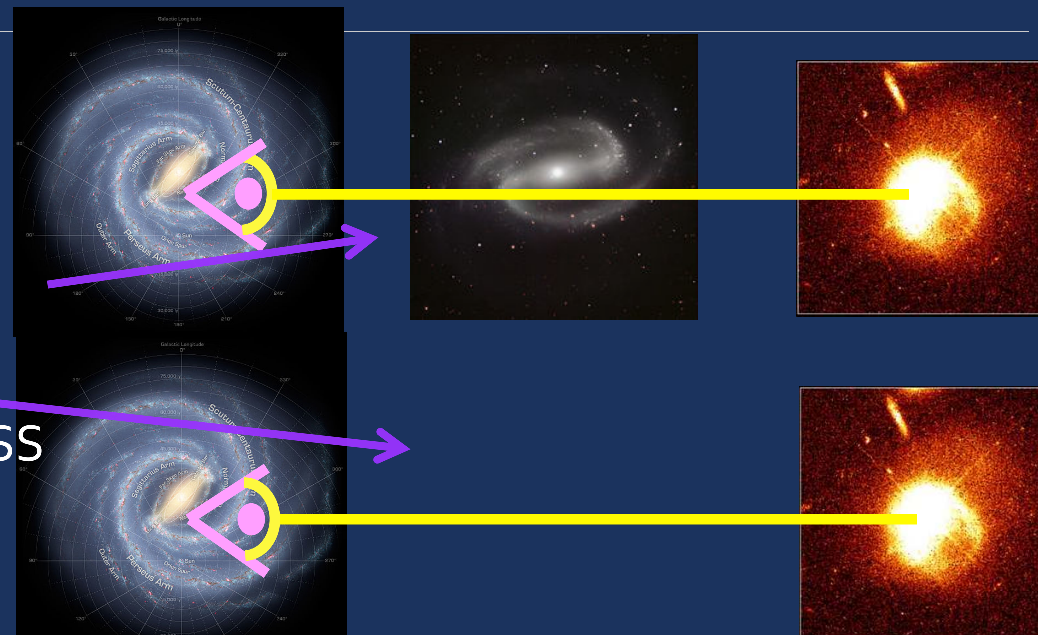
Simplest case:
$\varphi = RM = \Delta\chi/\Delta\lambda^2$

Polarization Angle:
$\chi = 0.5 \arctan(U/Q)$



Building a better sample of RMs for MgII absorbers

- VLA S-band (2-4 GHz)
- Observed 32 objects
  - 16 with MgII absorption, 16 without
  - 19 had previous RM from NVSS (Tayler +2009)



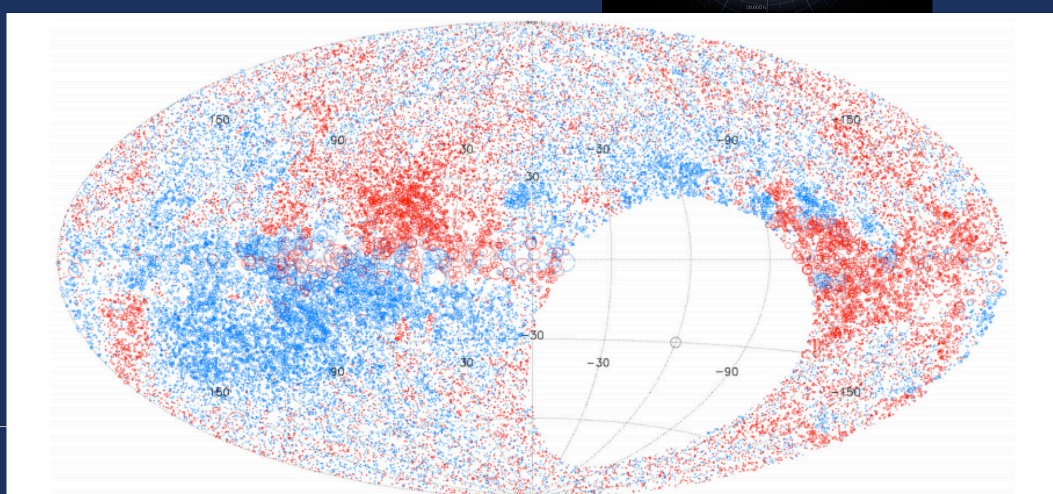


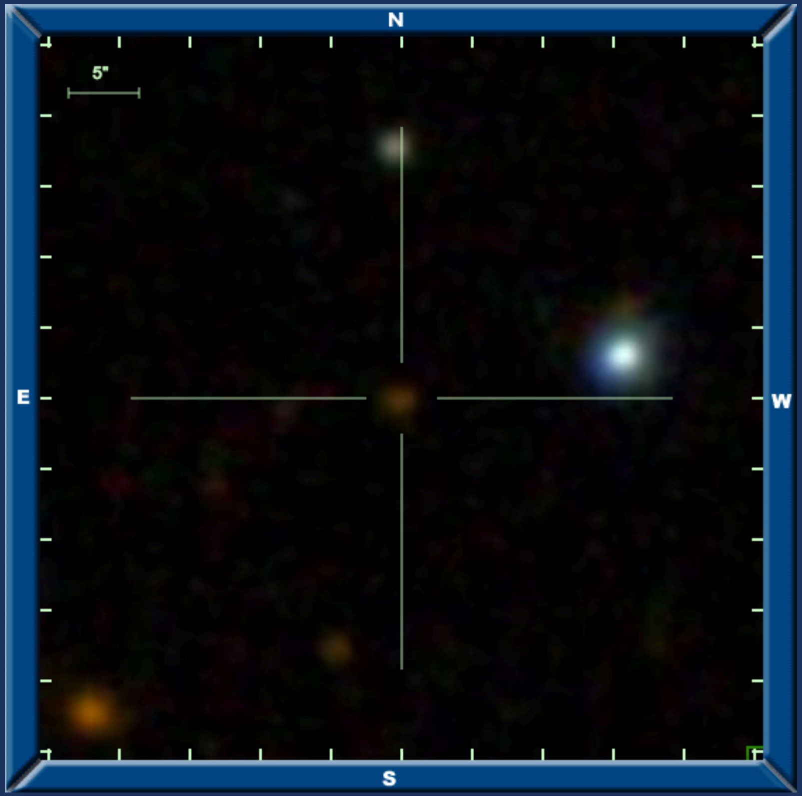
Figure 3. Plot of 37,543 RM values over the sky north of $\delta = -40°$. Red circles are positive rotation measure and blue circles are negative. The size of the circle scales linearly with magnitude of rotation measure.

RMs measured at ~1.4GHz

Taylor et al. 2009

Current VLA Observations

- 38 QSO sightlines with single MgII absorption feature AND photometric detection for absorber!
- $0.38 < z_{MgII} < 0.65$
- $0.65 < z_{QSO} < 1.9$
- 112 Control sightlines with roughly same distribution in RA and redshift
- **It is a statistical approach to get the mean properties of the CGM around galaxies; the same can be done with stacked HI absorption spectra.**



A. Williams et al 2017

Faraday Rotation – The IGrM

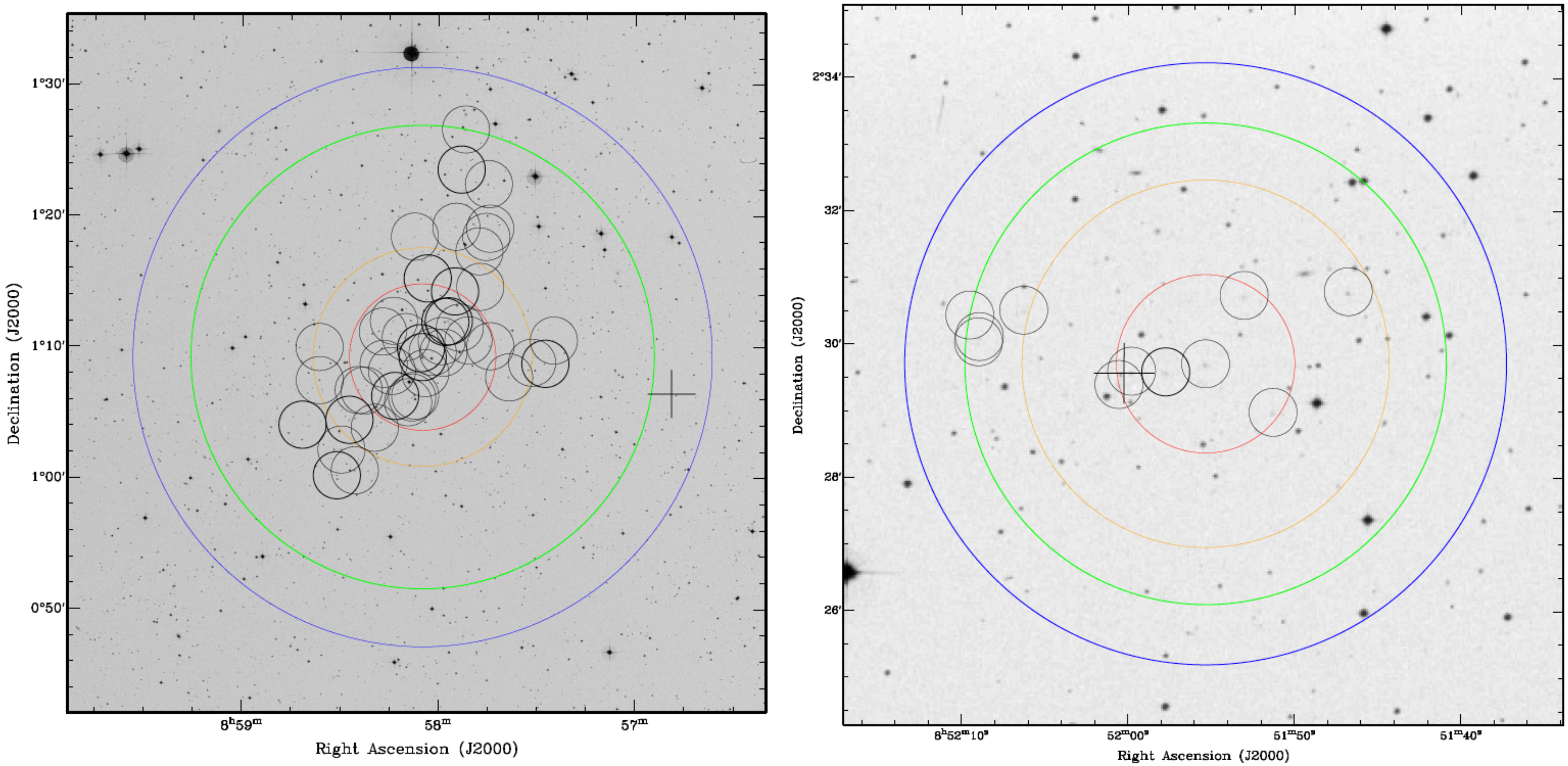


Figure 1. SDSS DR9 images of GAMA groups 100004 (*left*) and 100201 (*right*). The concentric rings represent the R_{50} (*red*), R_σ (*orange*), R_{100} (*green*) and our effective search radius out to which the crossmatch was carried ($1.25\times R_{100}$) (*blue*). The smaller, black circles circumscribe each group member's position as given in the catalogue of GAMA galaxies. The individual galaxies are difficult to see and the black circles are used as a representation for the group geometry. The black cross marks the position of the polarised radio source. 100004 is the largest multiplicity group that was matched with a polarised radio source (N = 45) and 100201 represents a scenario where the projection of the polarised radio source is close to the galaxy group centre, but is not a group member. I.P.(R_{50}) = 0.759 and has a small angular diameter distance to the nearest group member (25.3 kpc at z = 0.212). The redshift of the radio source is z = 1.1770±0.0022 (NED).

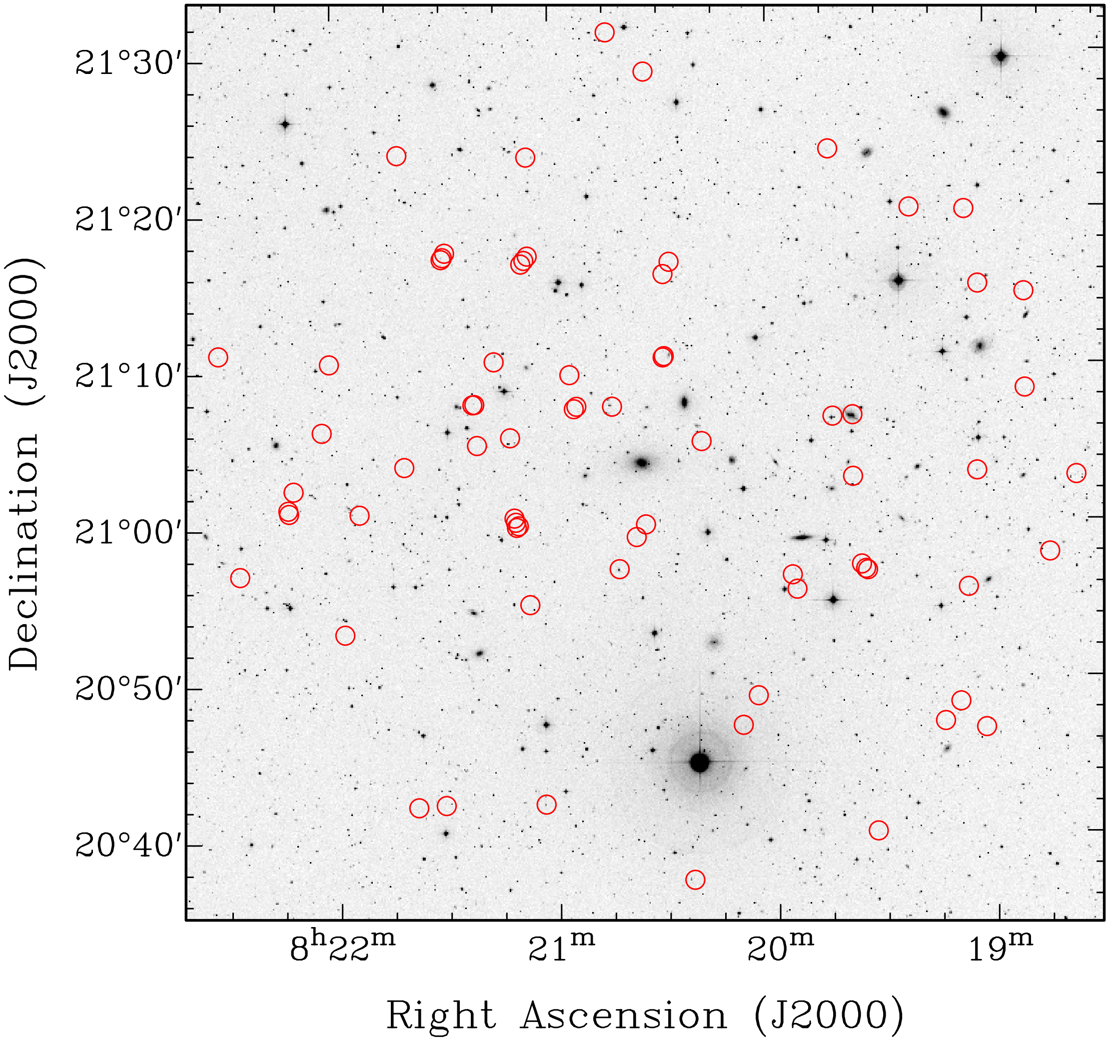
Kaczmarek+ 2017

Measuring the Intergalactic Medium in Groups

- Deeper RM surveys are coming both in targeted observations of samples of groups with the JVLA and ATCA as well as upcoming SKA precursor surveys that will establish full RM grids – **<u>and a similar approach can be used in HI absorption, particularly with stacking</u>**.

  - Groups harbor a significant baryonic content
  - The previously undetected IGM in groups could play an important role in driving the transformation of galaxies by stripping neutral gas out of galaxies.

NGC 2563 group – 32 sources > 2.3 mJy (77 down to FIRST sensitivity)



Wilcots, Williams, Kaczmarek

Summary

- Interesting astrophysics key to understanding the evolution of galaxies and their environments occurs at low HI column density – $N_{HI} < 10^{19}$ cm^{-2}
- Tracers at other wavelengths are extremely limited (e.g. insignificant numbers of bright UV quasars).
- The sensitivity of new radio surveys + the density of radio sources at fainter levels → potential for stacking large numbers of spectra to get mean HI absorption properties for a range of interesting environments.