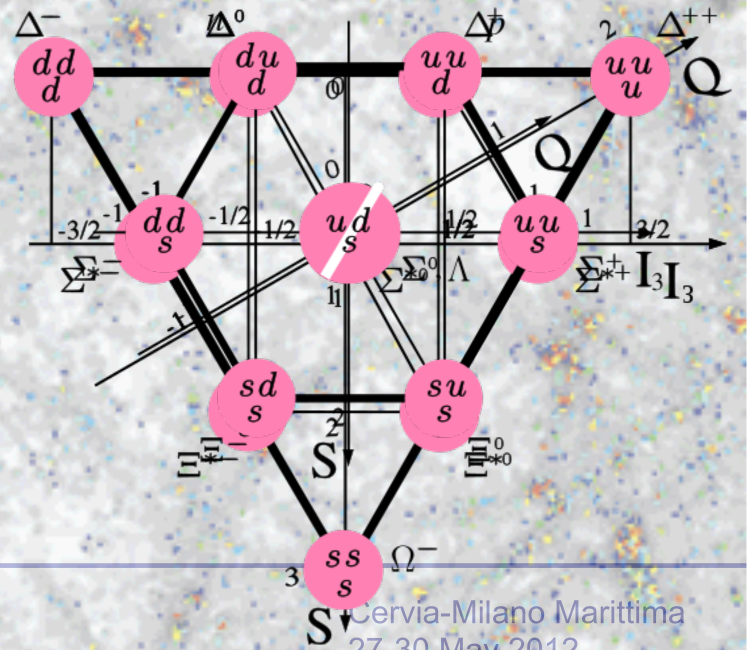
Missing in action:

Baryon census (2012) of the local universe

Joss Bland-Hawthorn
University of Sydney



Overview

Collapsed baryons (18%)

Uncollapsed baryons (82%)

2012 baryon census

- Galaxies
- Cold gas
- ICM

collapsed

- CGM

transition

- LyaF
- WHIM
- ? missing ?

uncollapsed

The way forward

Collapsed baryons – the story of galaxy formation over cosmic time

3000 > z > 1100, baryonic structure wiped out, DM structure remains

z ~ 1100, baryons respond to DM (CMB)

z ~ 200, baryons accrete onto DM minihalos

z ~ 30, first stars in DM minihalos

z ~ 10, reionization – first galaxies in DM minihalos

z ~ 3, "golden age" of accretion onto DM halos

z ~ 0.5, end of DM era, Λ starts to dominate

Uncollapsed baryons – a different set of problems

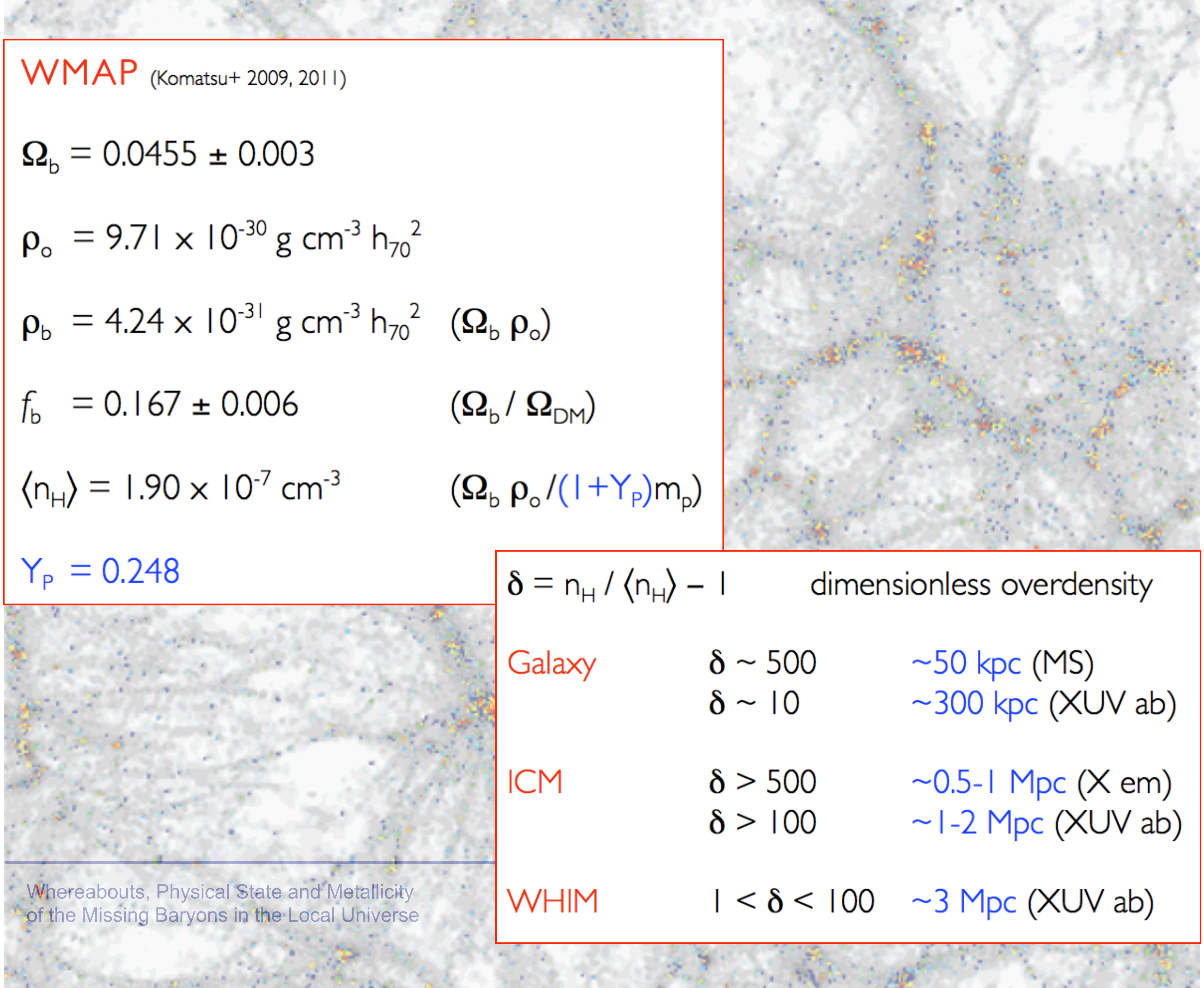
How do baryons decouple from dark matter ?

How do baryons move out of voids into filaments and sheets ?

How do baryons get into clusters, groups and galaxies ?

How do galaxy processes mess things up ?

Where are the missing baryons ?



WMAP (Komatsu+ 2009, 2011)

$\Omega_b = 0.0455 \pm 0.003$

$\rho_o = 9.71 \times 10^{-30}\ \mathrm{g\ cm^{-3}}\ h_{70}^{2}$

$\rho_b = 4.24 \times 10^{-31}\ \mathrm{g\ cm^{-3}}\ h_{70}^{2}$ $(\Omega_b\, \rho_o)$

$f_b = 0.167 \pm 0.006$ (Ω_b / Ω_{DM})

$\langle n_H \rangle = 1.90 \times 10^{-7}\ \mathrm{cm^{-3}}$ $(\Omega_b\, \rho_o / (1+Y_P) m_p)$

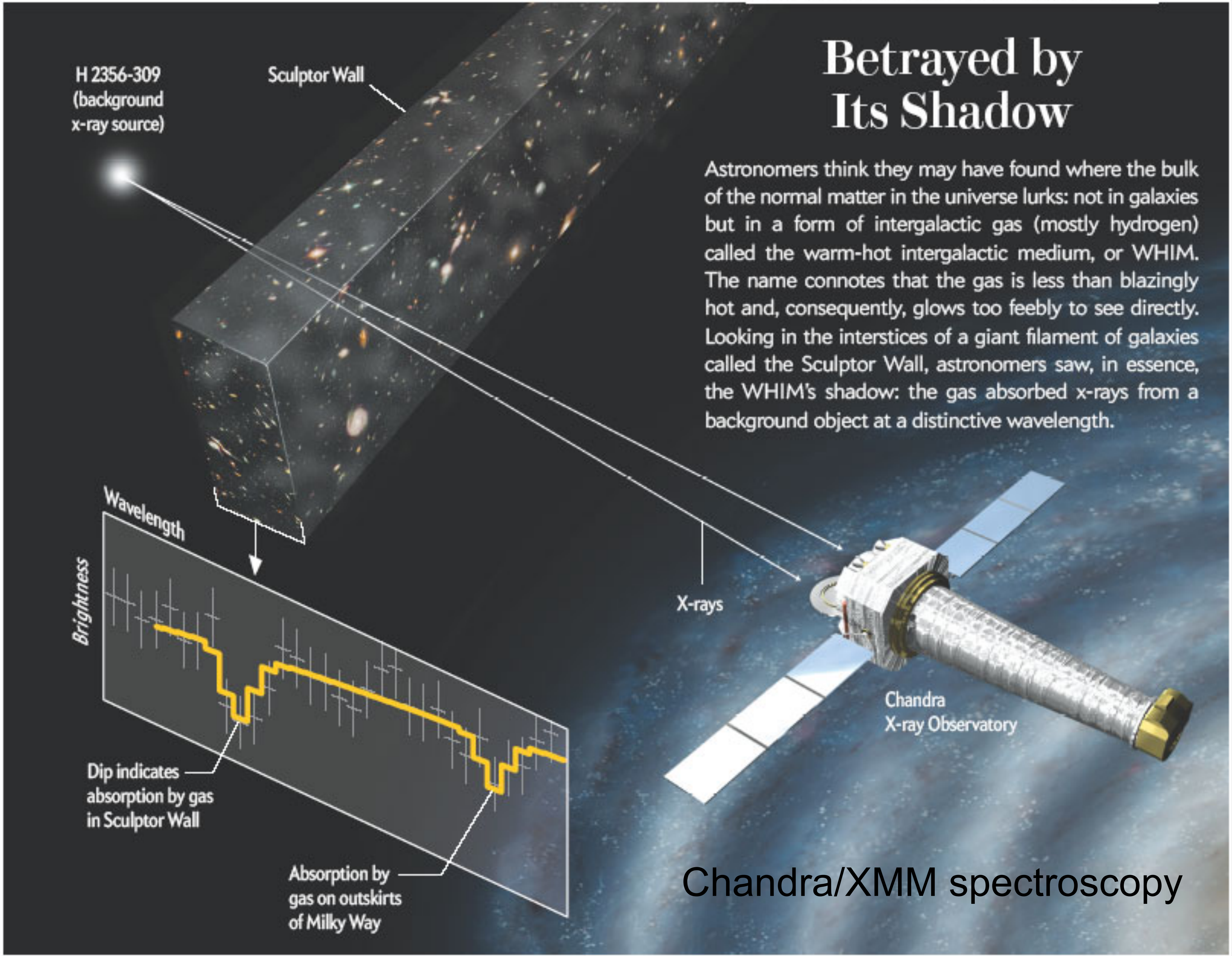
$Y_P = 0.248$

$\delta = n_H / \langle n_H \rangle - 1$ dimensionless overdensity

Galaxy	$\delta \sim 500$	~50 kpc (MS)
	$\delta \sim 10$	~300 kpc (XUV ab)
ICM	$\delta > 500$	~0.5-1 Mpc (X em)
	$\delta > 100$	~1-2 Mpc (XUV ab)
WHIM	$1 < \delta < 100$	~3 Mpc (XUV ab)

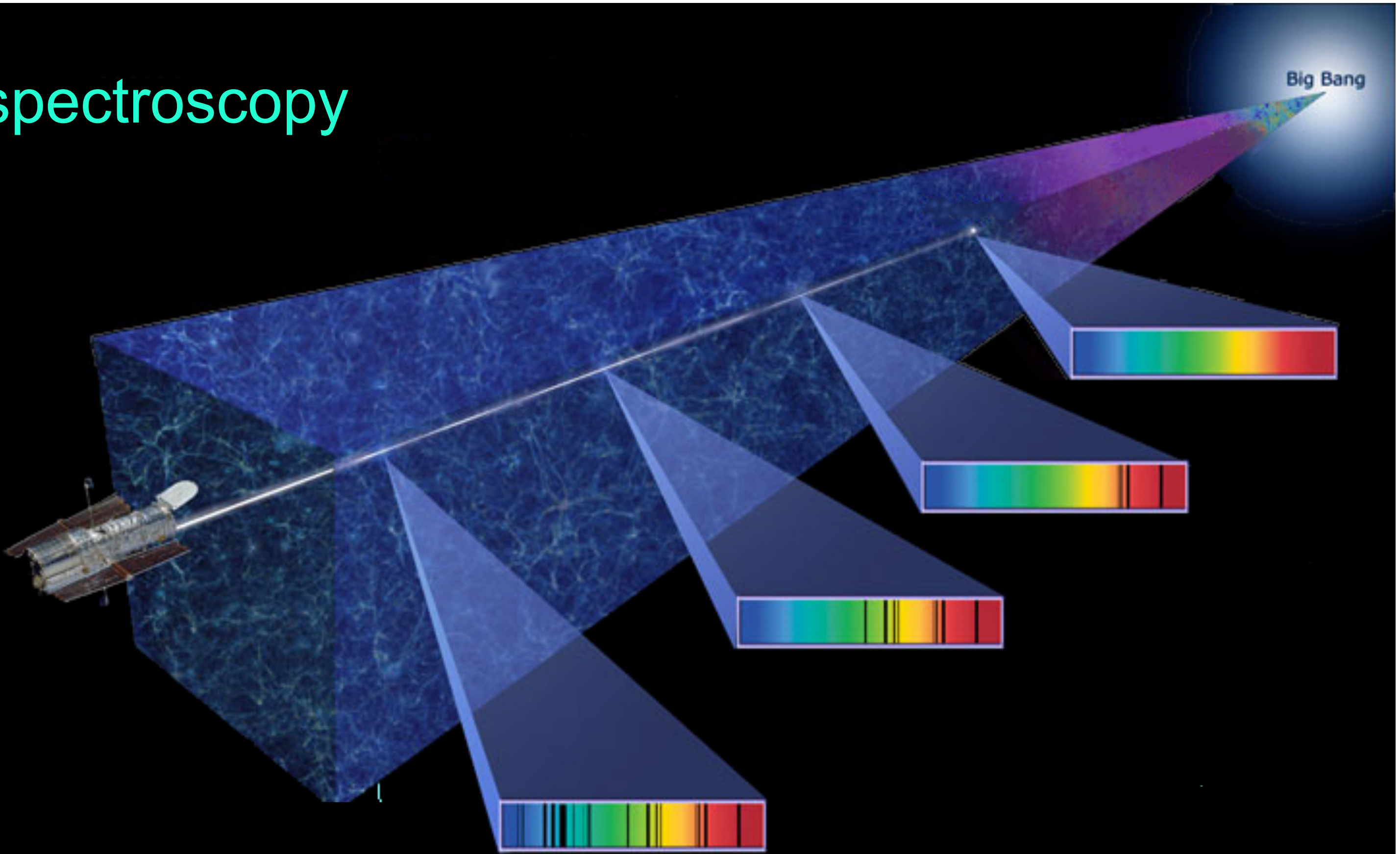
Betrayed by Its Shadow

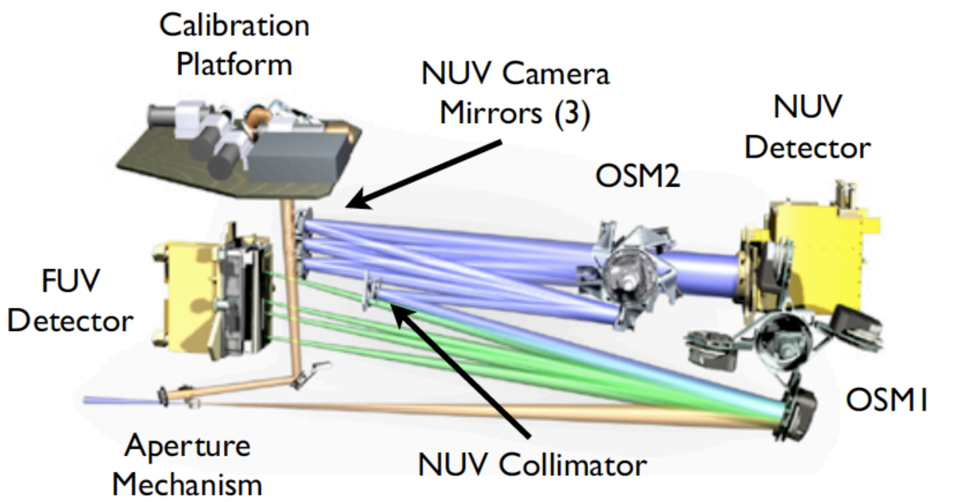
Astronomers think they may have found where the bulk of the normal matter in the universe lurks: not in galaxies but in a form of intergalactic gas (mostly hydrogen) called the warm-hot intergalactic medium, or WHIM. The name connotes that the gas is less than blazingly hot and, consequently, glows too feebly to see directly. Looking in the interstices of a giant filament of galaxies called the Sculptor Wall, astronomers saw, in essence, the WHIM's shadow: the gas absorbed x-rays from a background object at a distinctive wavelength.

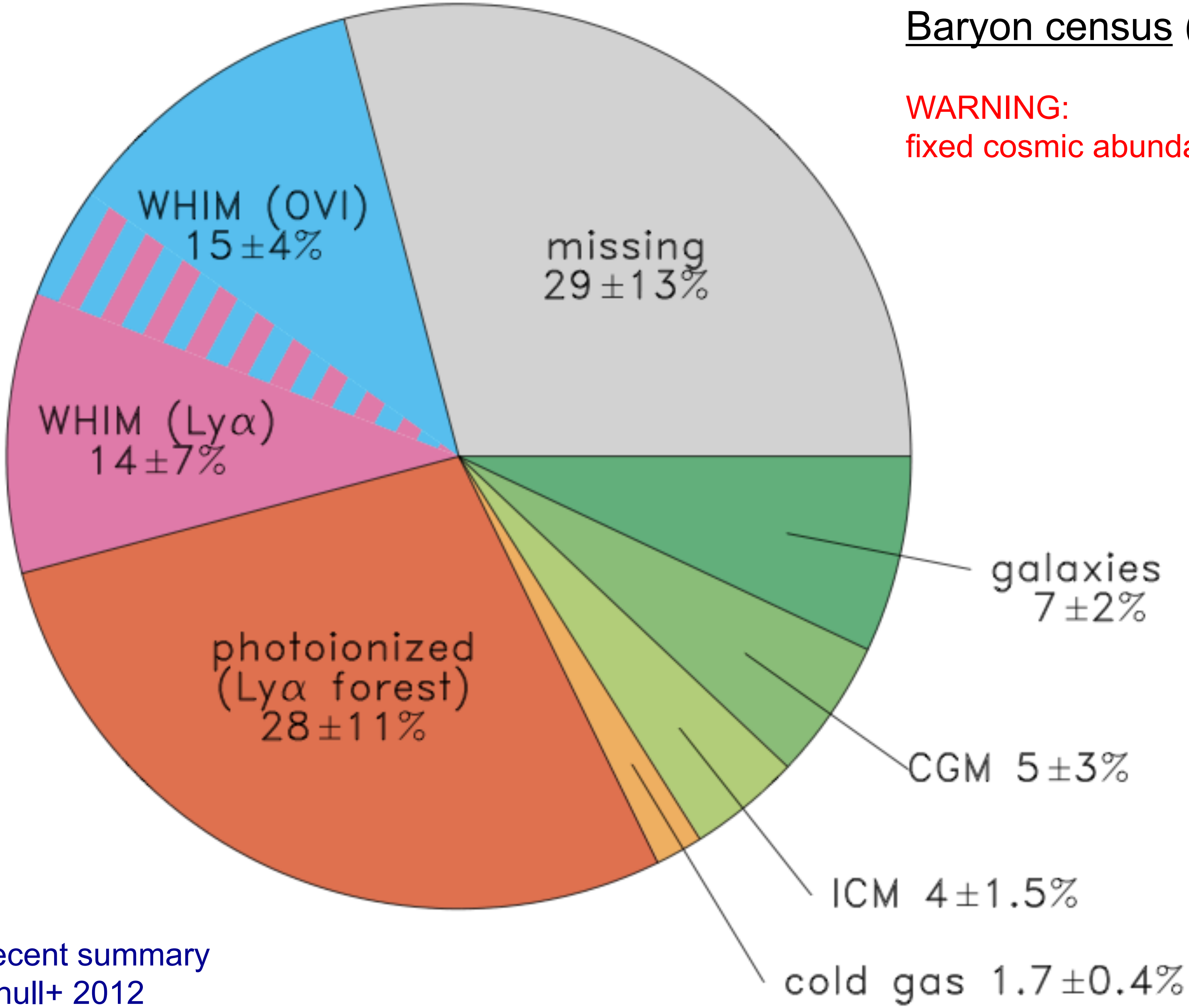


Chandra/XMM spectroscopy

HST COS UV spectroscopy







Baryon census (z~0)

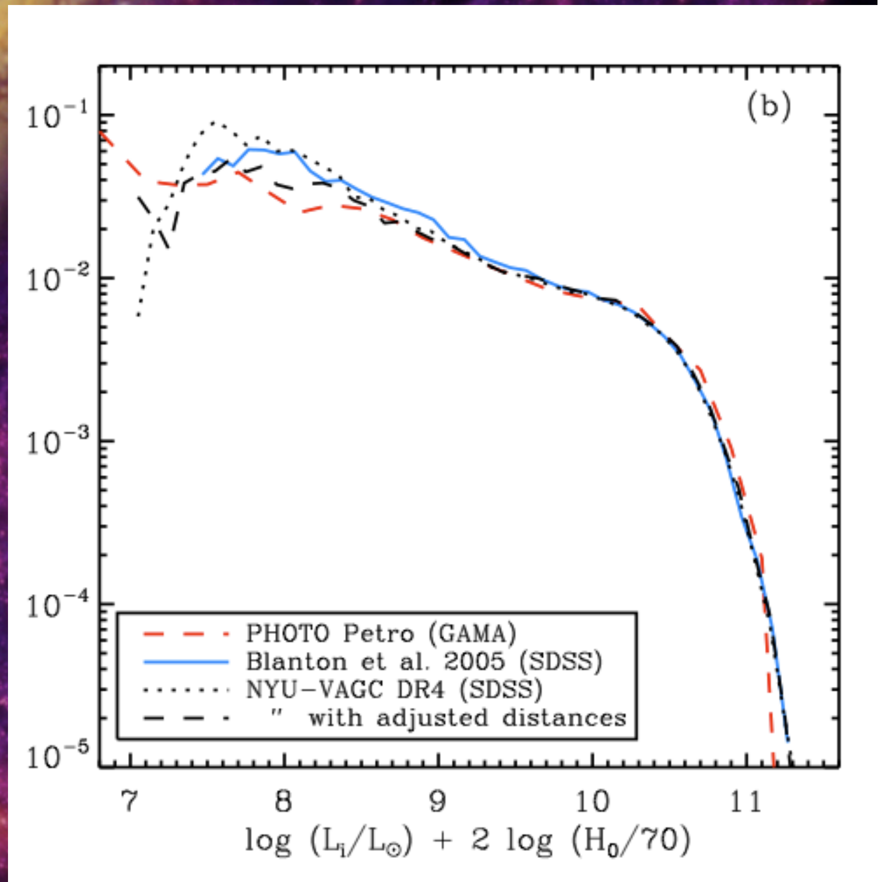
WARNING:
fixed cosmic abundances

Most recent summary
from Shull+ 2012

GALAXIES (7%)

Large galaxy surveys of the local universe – 2dFGRS, SDSS, MGC, GAMA (e.g. Baldry+12)

GF favours disks over spheroids 2:1 (Driver+07; cf. FHP96)



Cold gas (2%)

COLD GAS (2%)

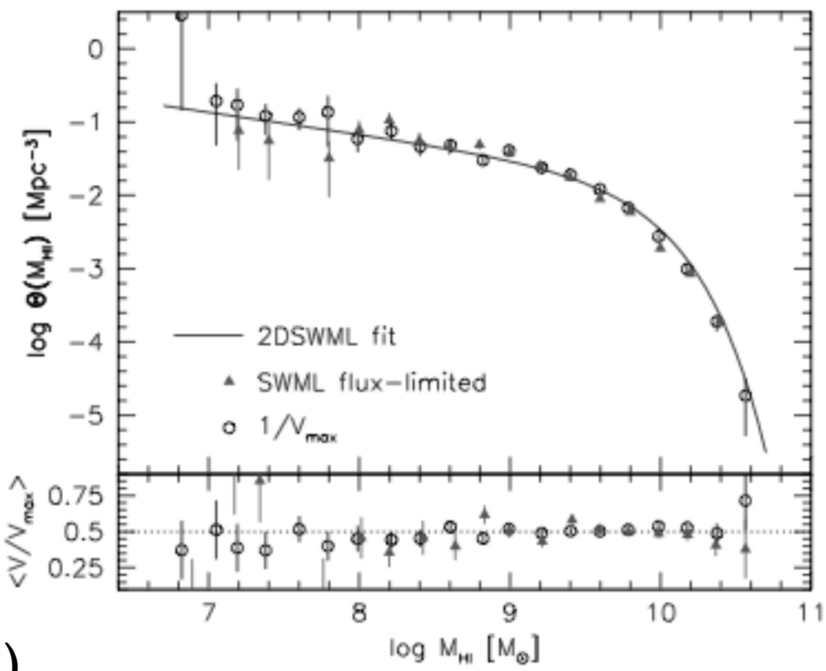
THE 1000 BRIGHTEST HIPASS GALAXIES: THE H I MASS FUNCTION AND $\Omega_{H\,I}$

M. A. Zwaan,[1] L. Staveley-Smith,[2] B. S. Koribalski,[2] P. A. Henning,[3] V. A. Kilborn,[4] S. D. Ryder,[5] D. G. Barnes,[1] R. Bhathal,[6] P. J. Boyce,[7] W. J. G. de Blok,[8] M. J. Disney,[8] M. J. Drinkwater,[9] R. D. Ekers,[2] K. C. Freeman,[10] B. K. Gibson,[11] A. J. Green,[12] R. F. Haynes,[2] H. Jerjen,[10] S. Juraszek,[12] M. J. Kesteven,[2] P. M. Knezek,[13] R. C. Kraan-Korteweg,[14] S. Mader,[2] M. Marquarding,[2] M. Meyer,[1] R. F. Minchin,[8] J. R. Mould,[15] J. O'Brien,[10] T. Oosterloo,[16] R. M. Price,[3] M. E. Putman,[17] E. Ryan-Weber,[1,2] E. M. Sadler,[12] A. Schröder,[18] I. M. Stewart,[18] F. Stootman,[6] B. Warren,[10] M. Waugh,[1] R. L. Webster,[1] and A. E. Wright[2]

Received 2002 December 3; accepted 2003 February 19

A

We present a new, accurate measurement of t
Galaxy Catalog, a sample of 1000 galaxies with
hemisphere. This sample spans nearly 4 orders o
10.6] and is the largest sample of H I–selected ga
technique to measure the space density of galaxi
effects of large-scale structure. The resulting H I
function with faint-end slope $\alpha = -1.30$. This sl
late-type galaxies giving steeper slopes. We exten
tion of the H I mass function, including peculiar r
inclination effects, and we quantify these biases.
ment of the cosmological mass density of neutral
galaxies contribute only ~15% to this value, cons



corrected for cold He I, H_2 (FP04)

Confirmation: ALFALFA survey (Darling+11)

COLD GAS (2%)

missing H_2 ?

A Heavy Baryonic Galactic Disc

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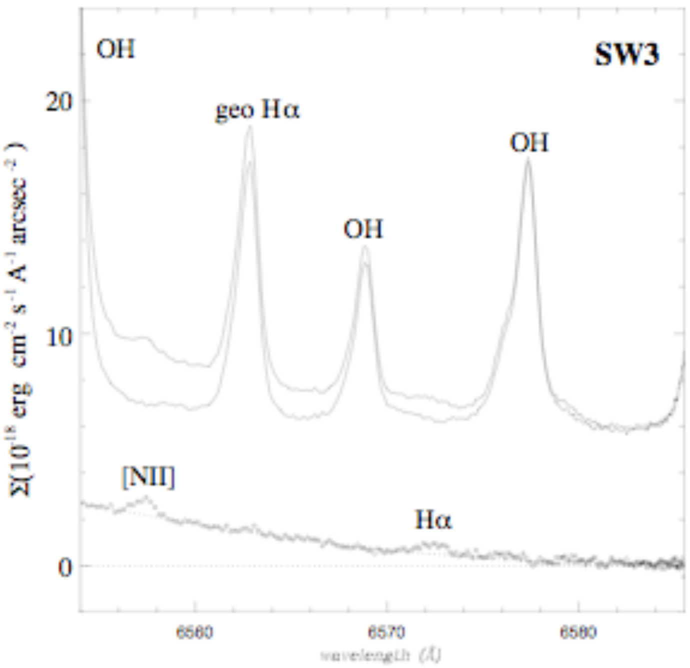
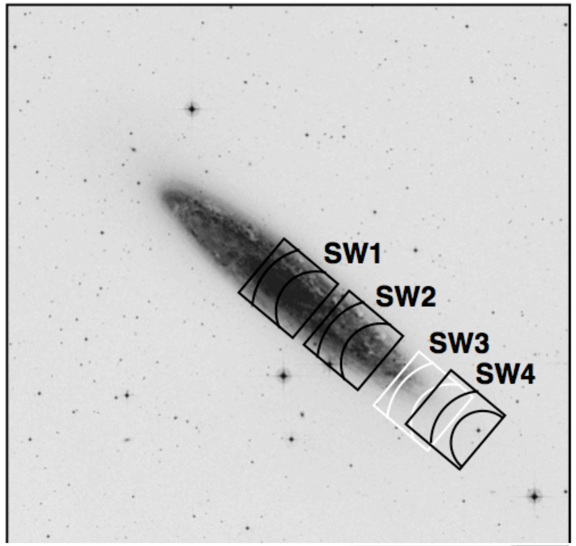
April, 2012.

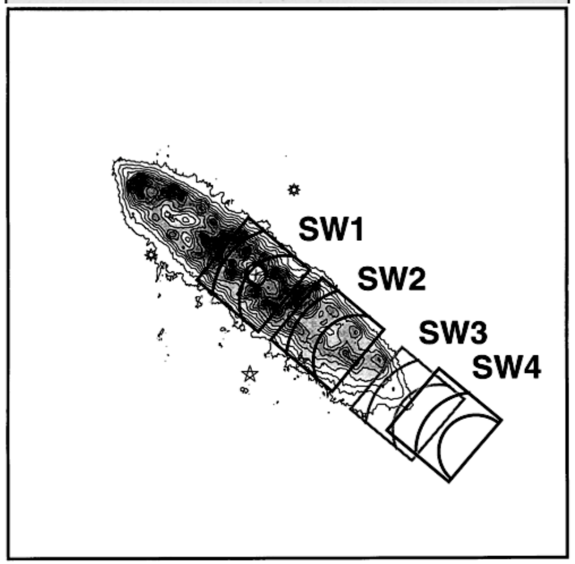
Abstract

We investigate the possibility that the observed rotation of galaxies can be accounted for by invoking a massive baryonic disc with no need for non-baryonic dark matter or a massive halo. There are five primary reasons for suggesting this possibility. Firstly, that there are well known disc surface mass density distributions that naturally produce the observed rotation curves of galaxies. Secondly, that there are a number of rotation curve 'puzzles' that cannot be explained by a massive dark matter halo i.e. the success of maximum disc fitting, HI gas scaling to the observed rotation, the disc/halo conspiracy and the interpretation of the Tully-Fisher relation. Thirdly, recent 21cm observations show an almost constant HI surface density and a distinct 'cut-off' or edge to galactic discs. We explain this constant surface density in terms of either an optical depth effect or the onset of molecular gas formation and hence the possibility of considerably more gas existing in galaxies than has previously been thought. We suggest that the HI cut-off does indeed mark the edge of the galactic disc. Fourthly, there have recently been an increasing number of observations, most importantly γ-ray observations, that imply that X_{CO} may be ten times higher in the outer Galaxy. This 'dark' gas may provide adequate mass to account for galaxy rotation. Finally, we show that the additional baryonic mass required to account for the rotation of galaxies is just that required to reconcile observed baryons with those predicted by big bang nucleosynthesis without having to invoke a massive warm inter-galactic medium. We reconsider Mestel's ideas about the collapse of isothermal and constant density spherical clouds and show that these can be simply used to successfully model the rotation of galaxies. Mestel discs can also be used to straight forwardly explain the scaling laws of galaxies, particularly the observed relation between rotation velocity and radius and the oft used Tully-Fisher relation. Thus the observed gross properties of disc galaxies can be explained by the monolithic collapse of baryonic gas into a rotationally supported disc. We discuss observations of the baryonic content of galactic discs and where sufficient 'hidden' baryons might be found to account for the rotation.

H+ is found <u>beyond</u> the HI edge consistent with low column HI being ionized by an external medium





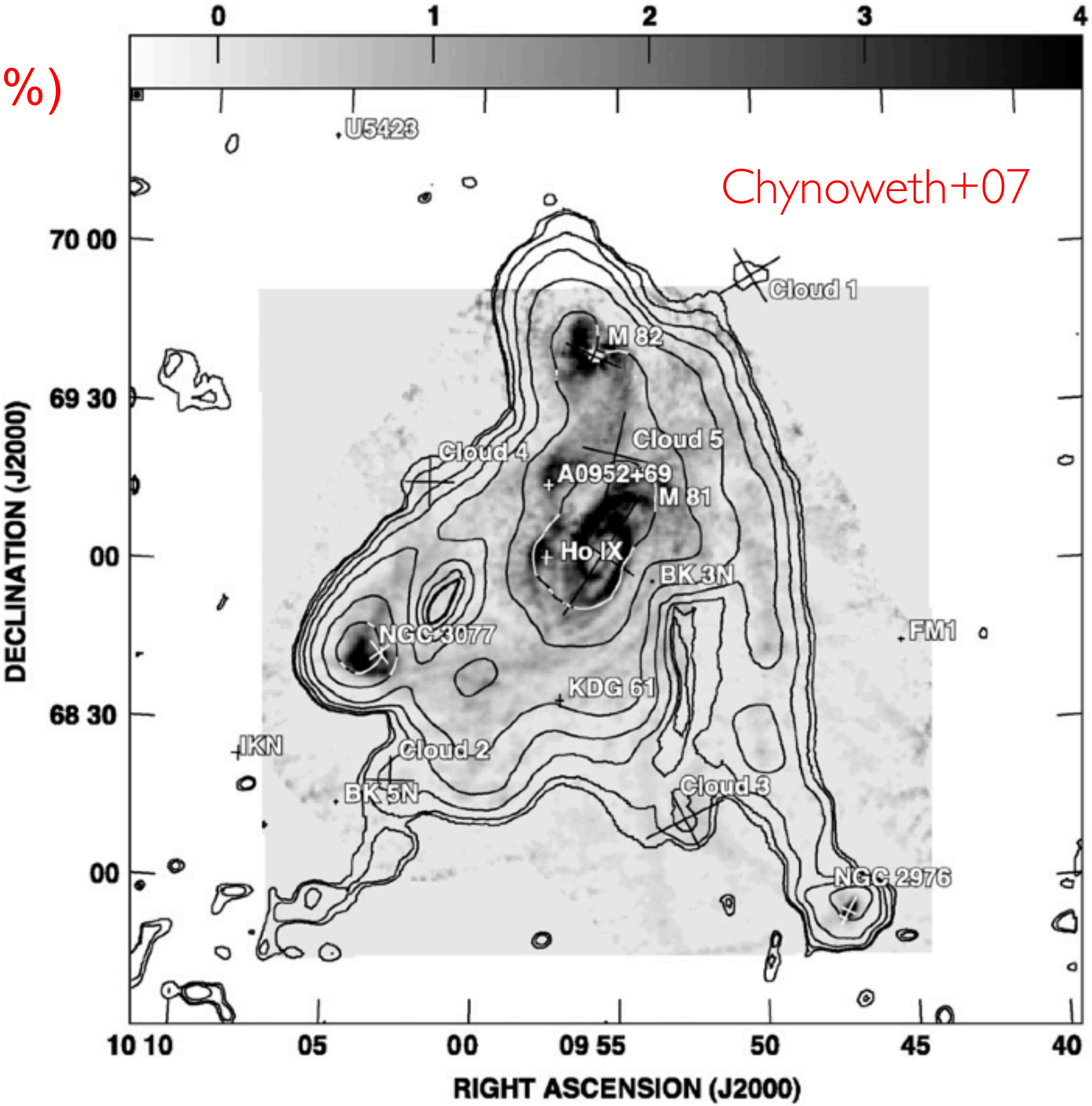


These are <u>very</u> time-consuming observations.

JBH, Freeman & Quinn 1997

Christlein, Zaritsky & JBH 2010

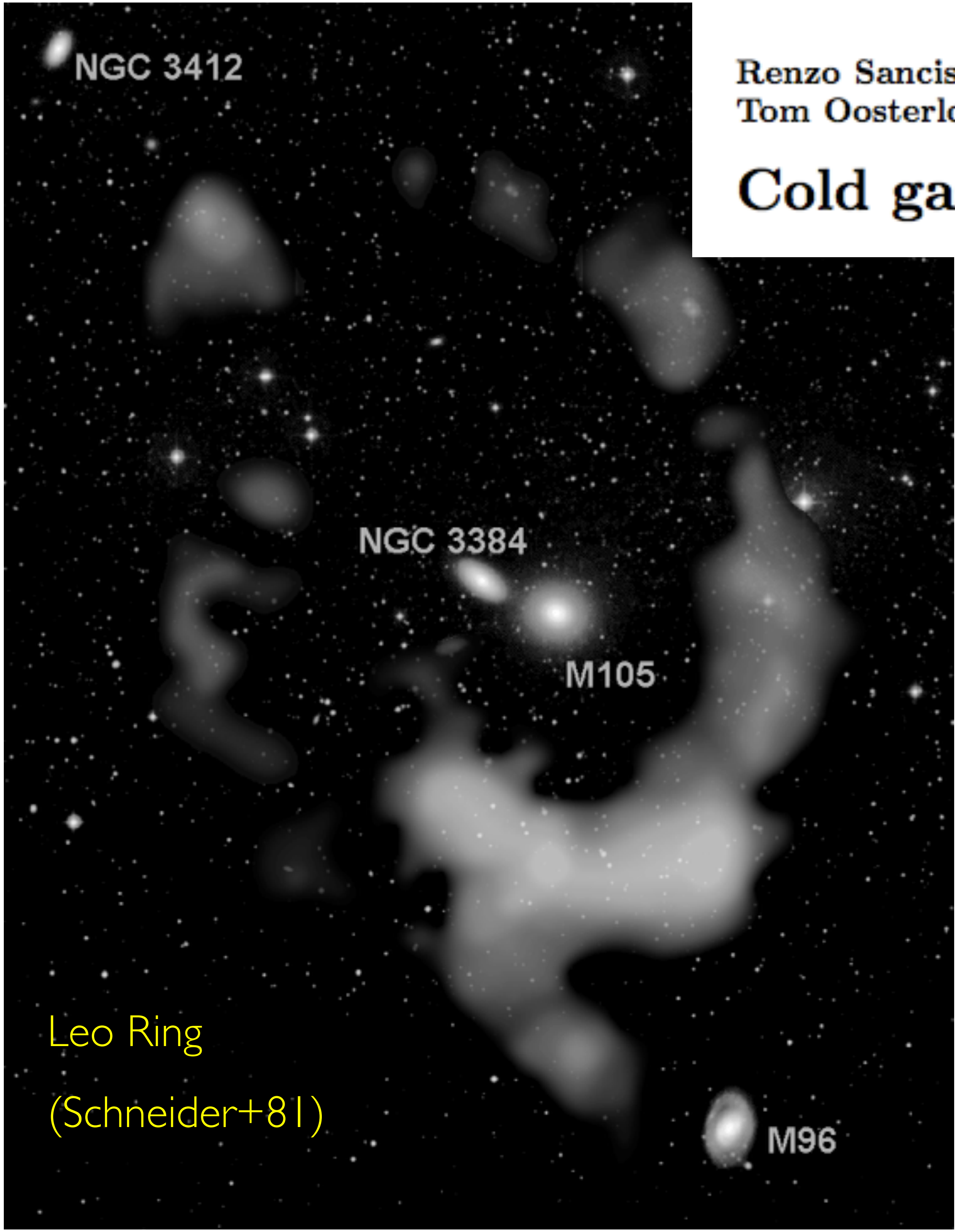
COLD GAS (2%)



0
1
2
3
4
U5423
Chynoweth+07
70 00
69 30
00
68 30
00
Cloud 1
M 82
Cloud 5
Cloud 4
A0952+69
M 81
Ho IX
BK 3N
NGC 3077
FM1
KDG 61
IKN
Cloud 2
BK 5N
Cloud 3
NGC 2976
DECLINATION (J2000)
10 10
05
00
09 55
50
45
40
RIGHT ASCENSION (J2000)

Renzo Sancisi · Filippo Fraternali ·
Tom Oosterloo · Thijs van der Hulst

Cold gas accretion in galaxies



<u>Sancisi dictat:</u> All cold gas is associated with galaxies (i.e. dark matter)

Primordial HI clouds (cf. Blitz+99) or tidal interaction ?

COLD GAS (2%)

Circumgalactic media (5%)

– the new frontier –

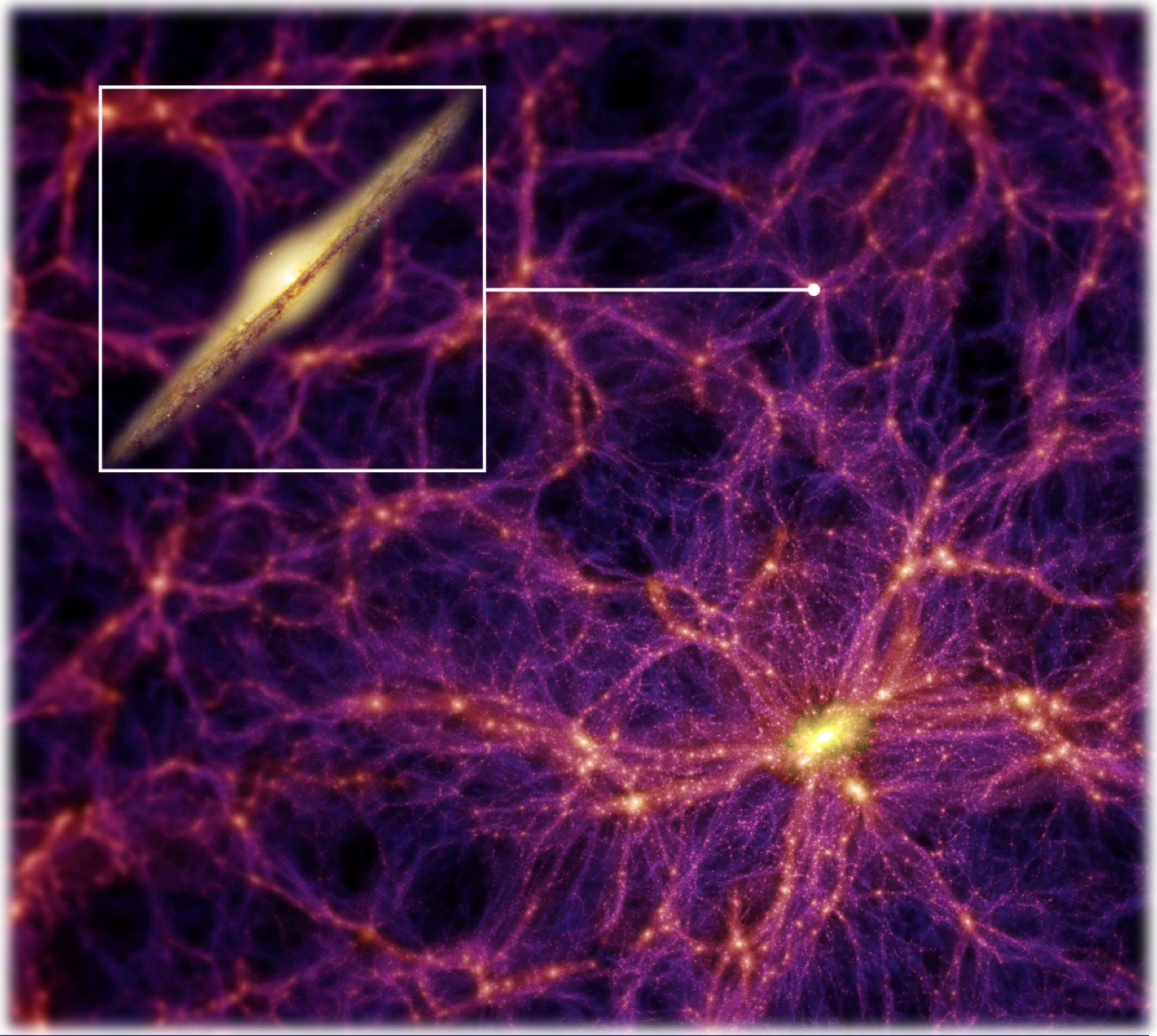
CGM – Why the new frontier?

It may soon be possible to resolve how gas gets into galaxies:

Coherent flows?

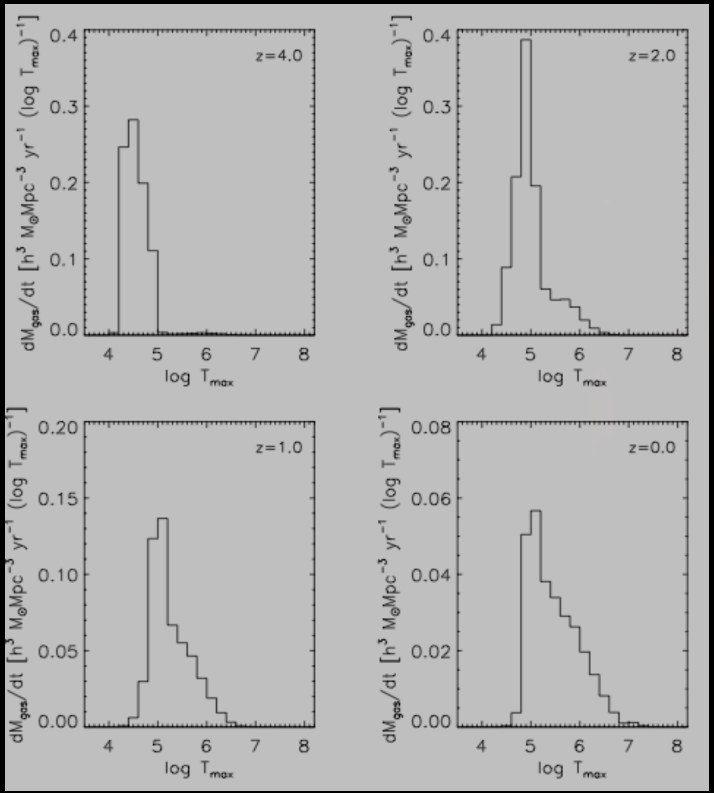
Cosmic rain?

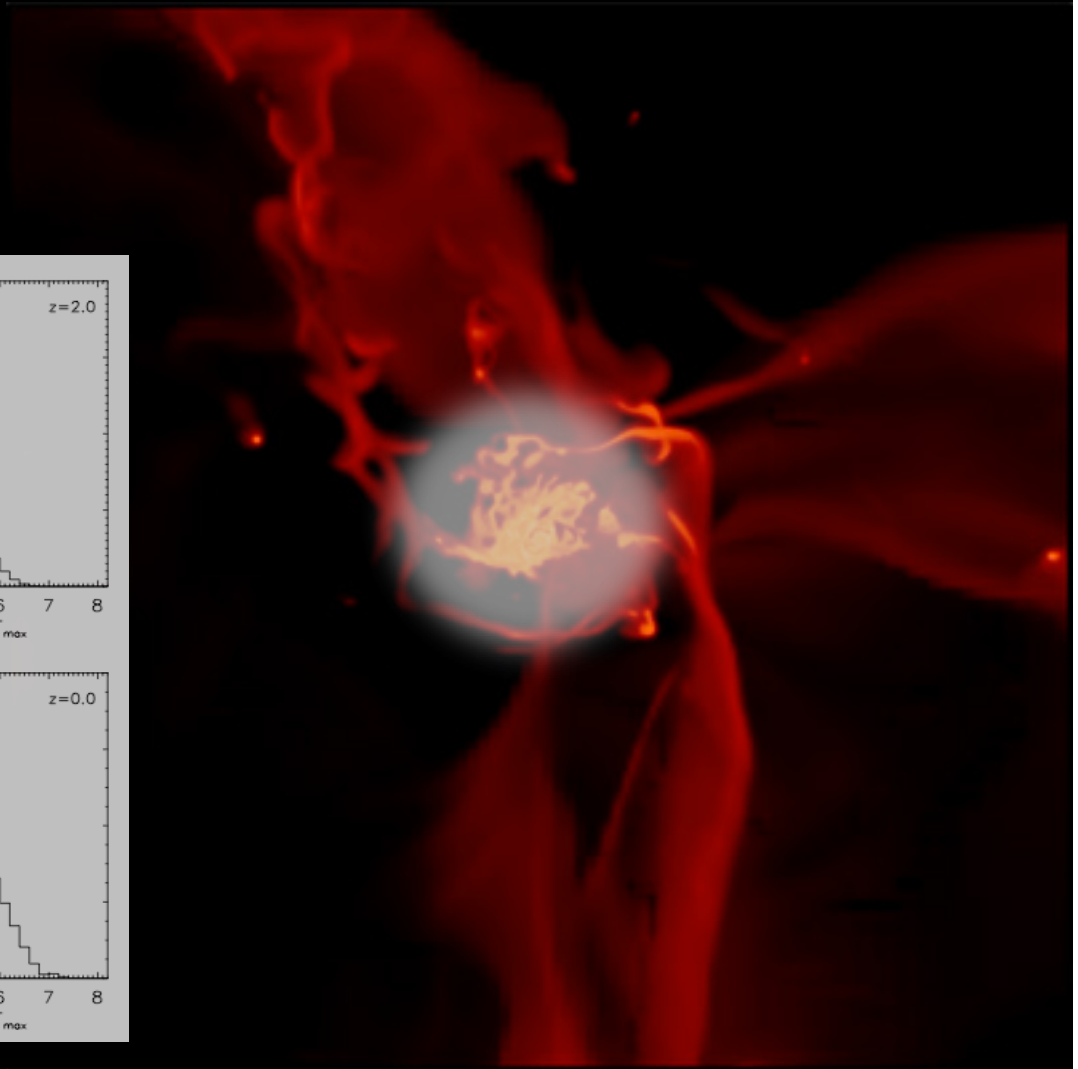
Something else?



Do cold flows exist? Are they figments of our imaginative simulations?

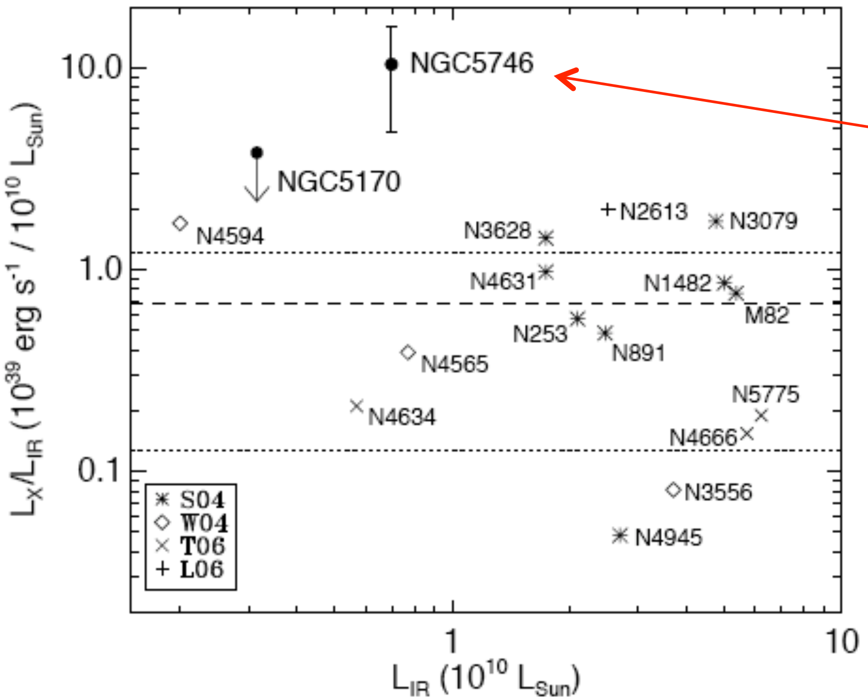
Keres+ 2005, 2009



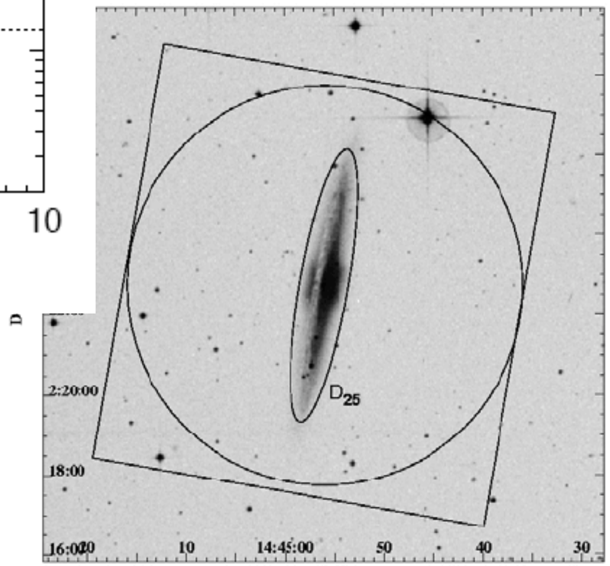


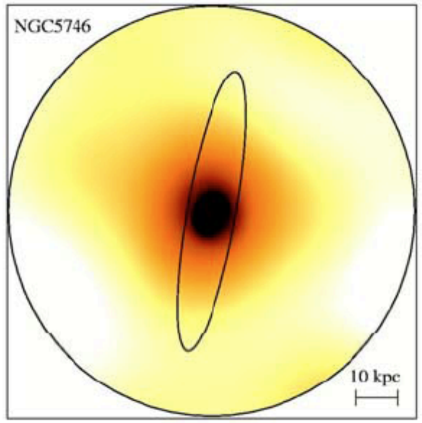
Discovery of a very extended X-ray halo around a quiescent spiral galaxy – the "missing link" of galaxy formation

Pedersen+ 06; Rasmussen+ 06



not confirmed





Detection of a Hot Gaseous Halo Around the Giant Spiral Galaxy NGC 1961 (2011)

$V_{rot} \sim 400$ km/s

Michael E. Anderson[1], Joel N. Bregman[1]

Al

Hot gaseous halos are predictec
important for our understanding of
detected at distances beyond a fev
Chandra ACIS-I instrument to sear
candidate galaxy: the isolated gian
rants around the galaxy for 30 ks
point source emission, and found d
50 kpc. We fit β-models to the emis
kpc of $5 \times 10^9 M_\odot$. When this profile
virial radius), the implied hot halo r
assume a gas metallicity of $Z = 0.5$
of gas, but falls significantly below
searches, and suggests that NGC 1
the cosmic mean, which would tent
baryon Tully-Fisher relationship of
gas is no more than 0.4 $M_\odot$/year,

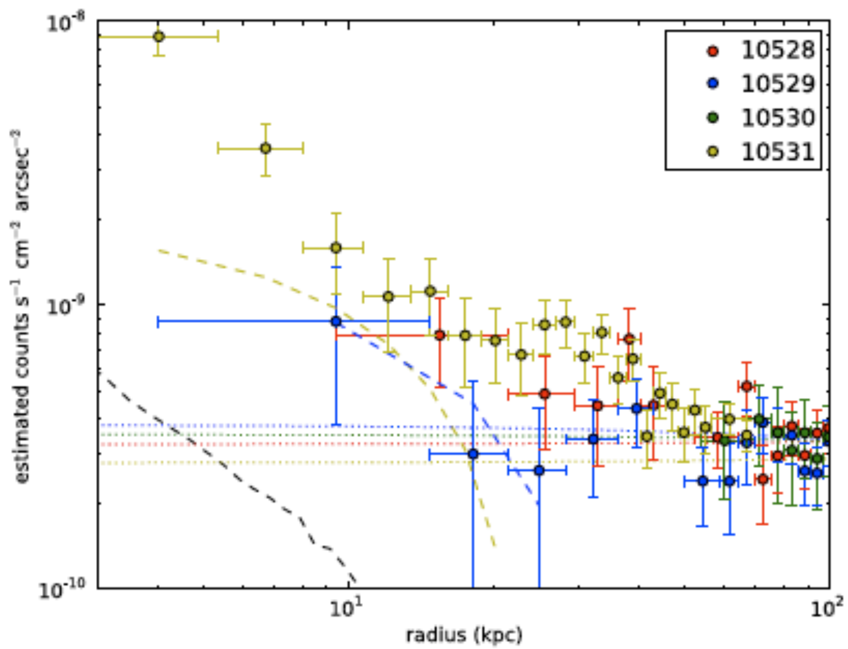


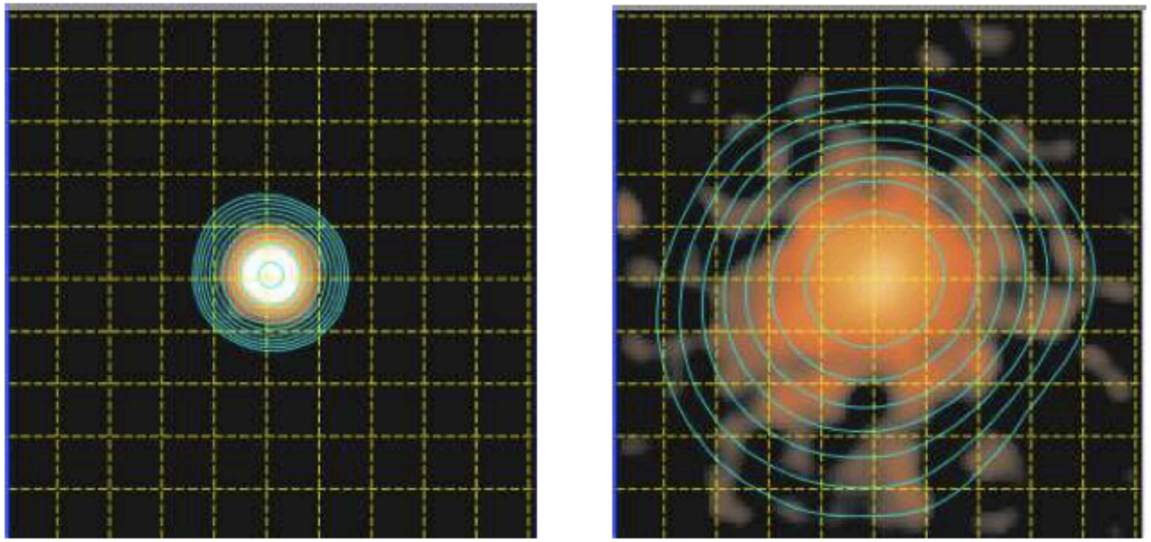
Fig. 5.— Log-log plot of radial surface brightness profiles for all four observations. The black dashed line is the estimated contribution of stars, and the colored dashed lines are the estimated contributions of X-ray binaries. The colored data points are the surface brightness profile with resolved and unresolved point sources subtracted. Unlike Figures 3 and 4, we have not subtracted the sky X-ray background from the surface brightness profile. The smoothed sky X-ray background is indicated by the four dotted colored lines. We detect emission above the background out to 40-50 kpc which is more spatially extended than the other galactic components.

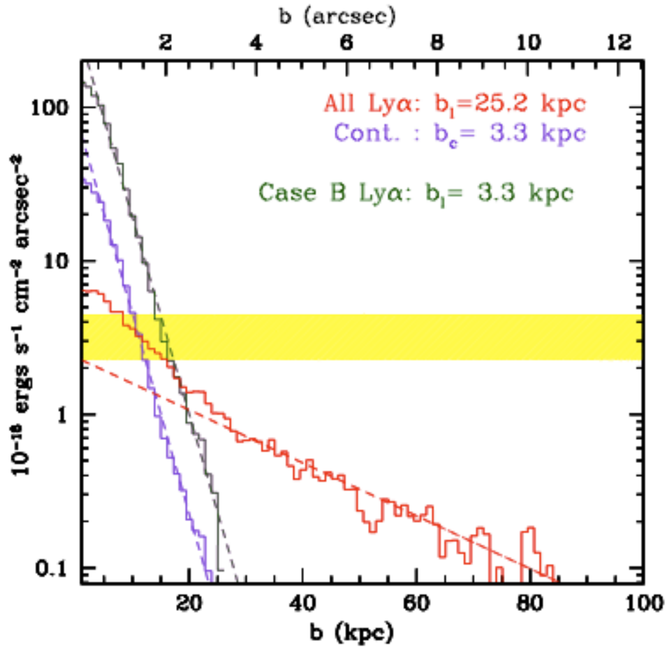
see also Dai+12 (UGC 12591; $V_{rot} \sim 470$ km/s)

Circumgalactic media (5%)

Lyα halos at z~3 – 92 LBGs stacked

Steidel et al.

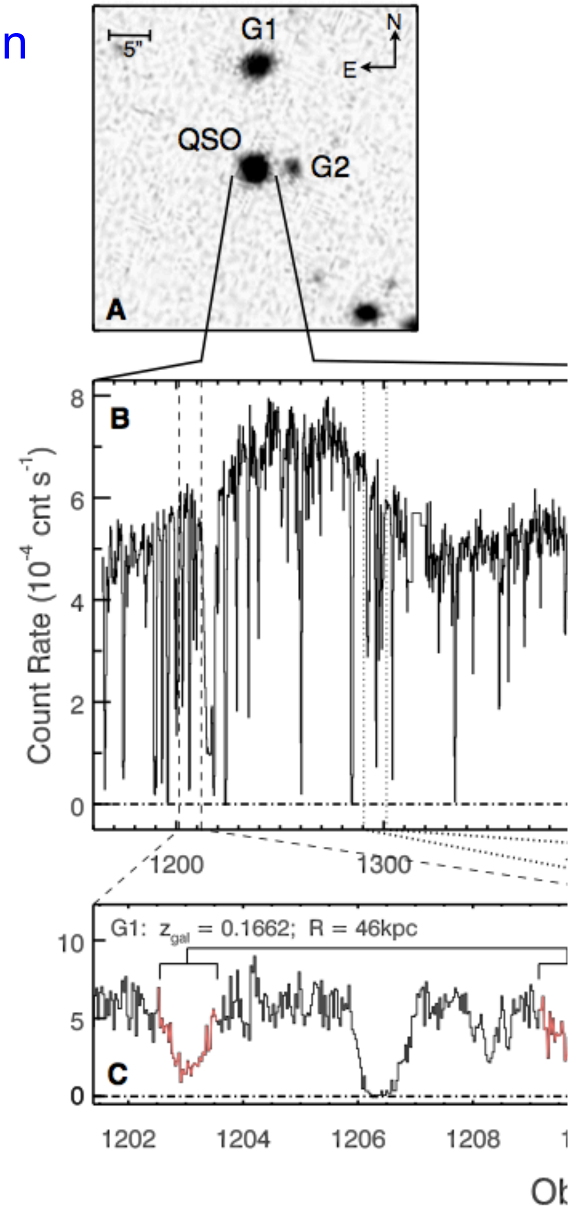


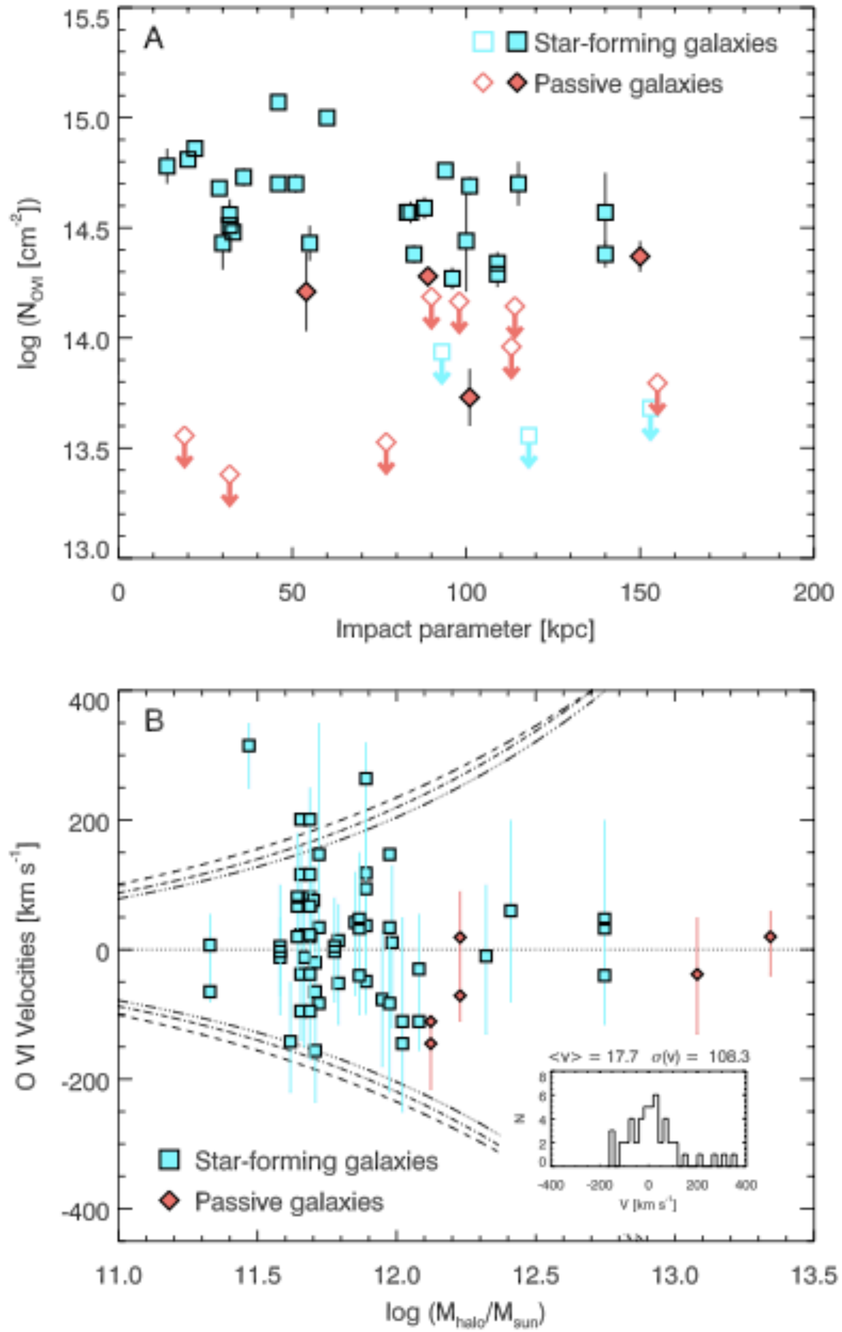


Circumgalactic media (5%) See alsc

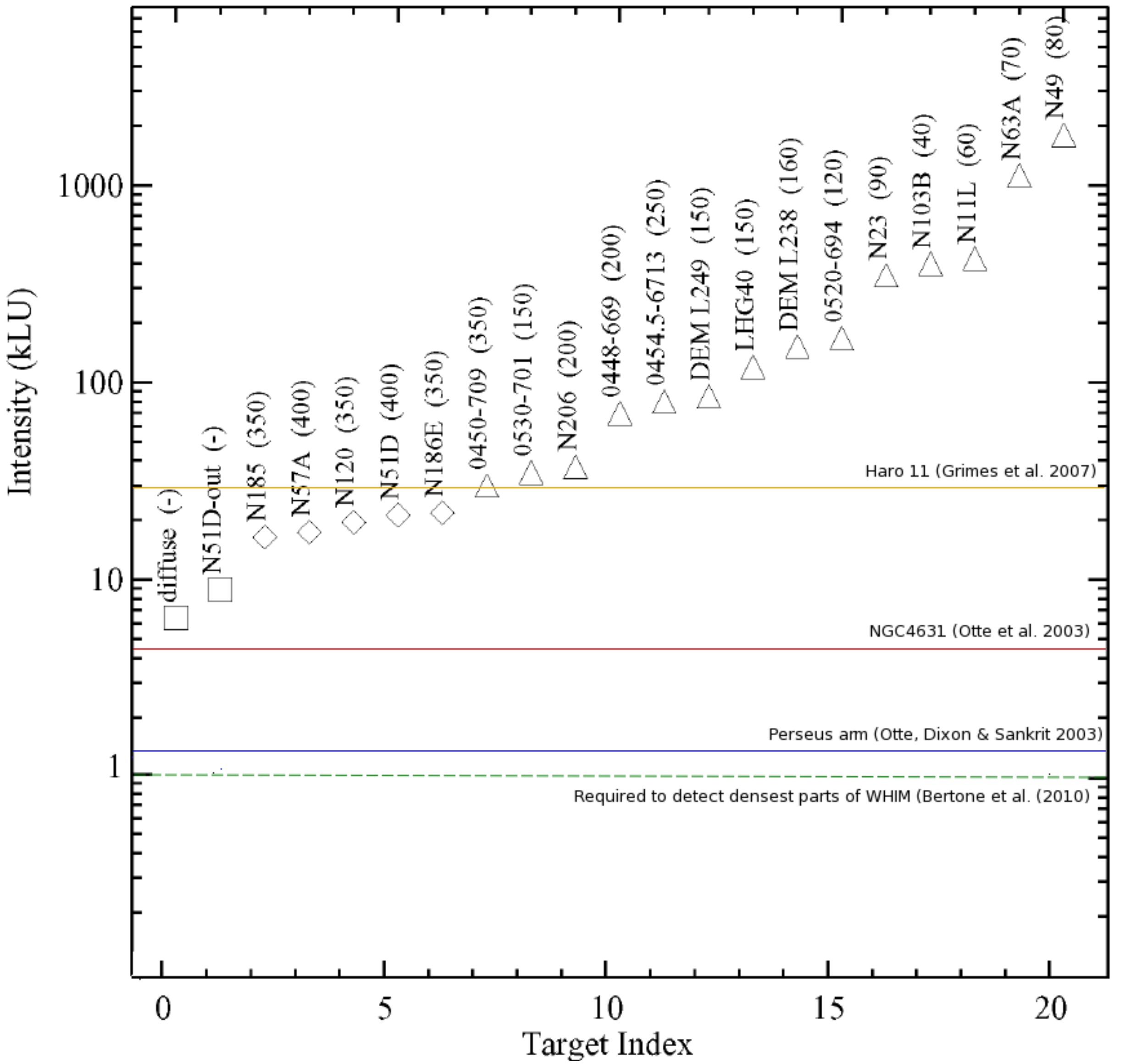
OVI absorbers in
z=0.1-0.4
L★ galaxies

(Tumlinson+11)





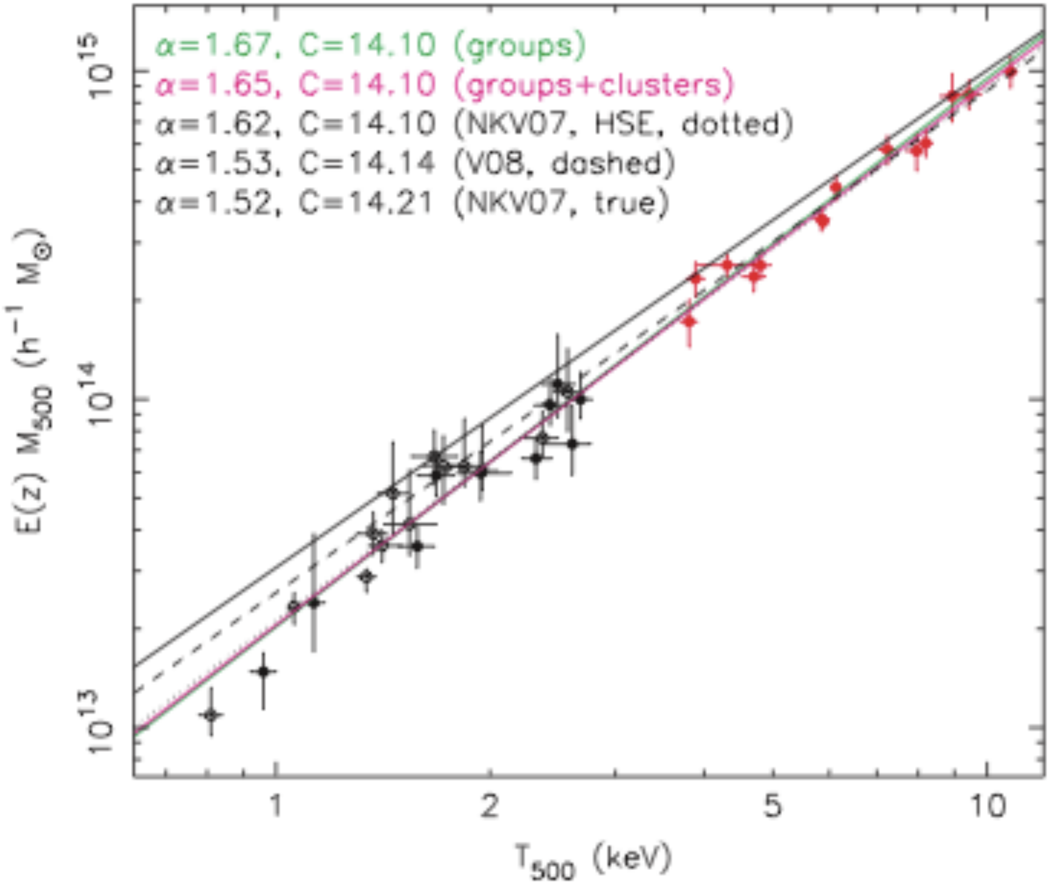
OVI emission



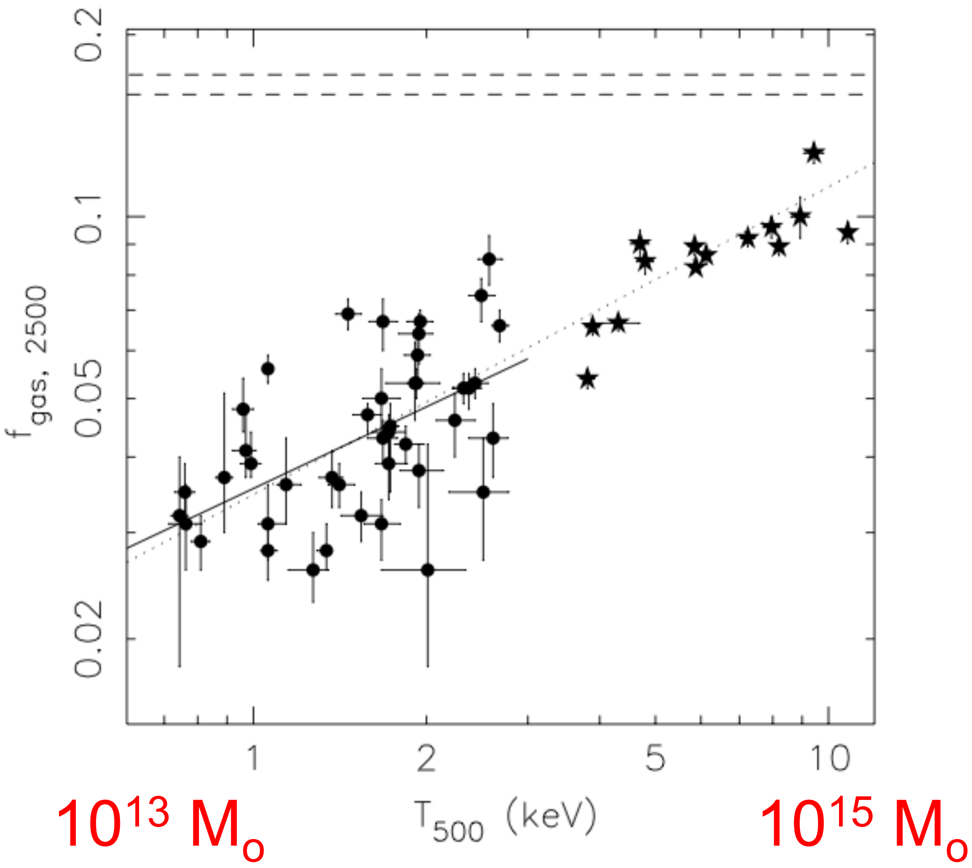
Most of WHIM below 0.1 kLU (Marcolini+05)

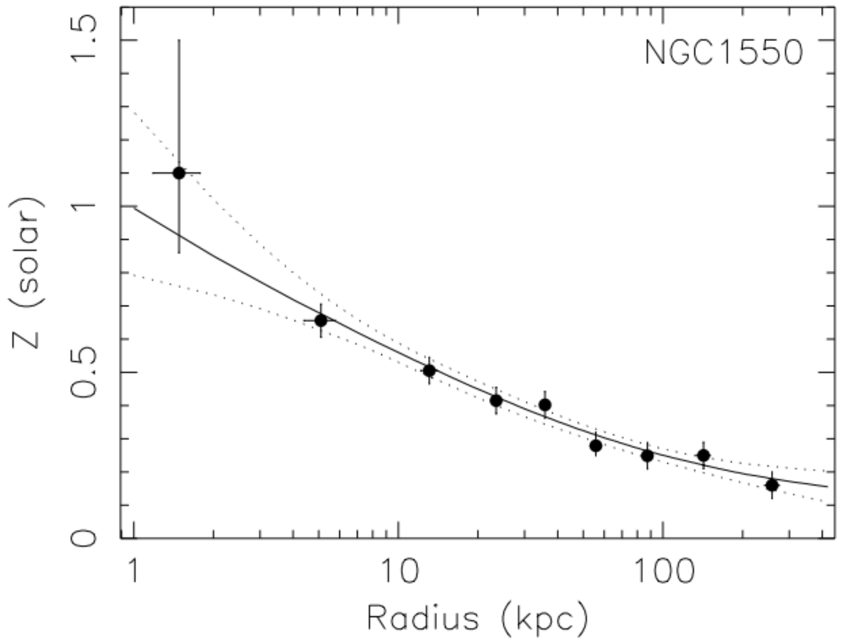
INTRACLUSTER MEDIA (4%)

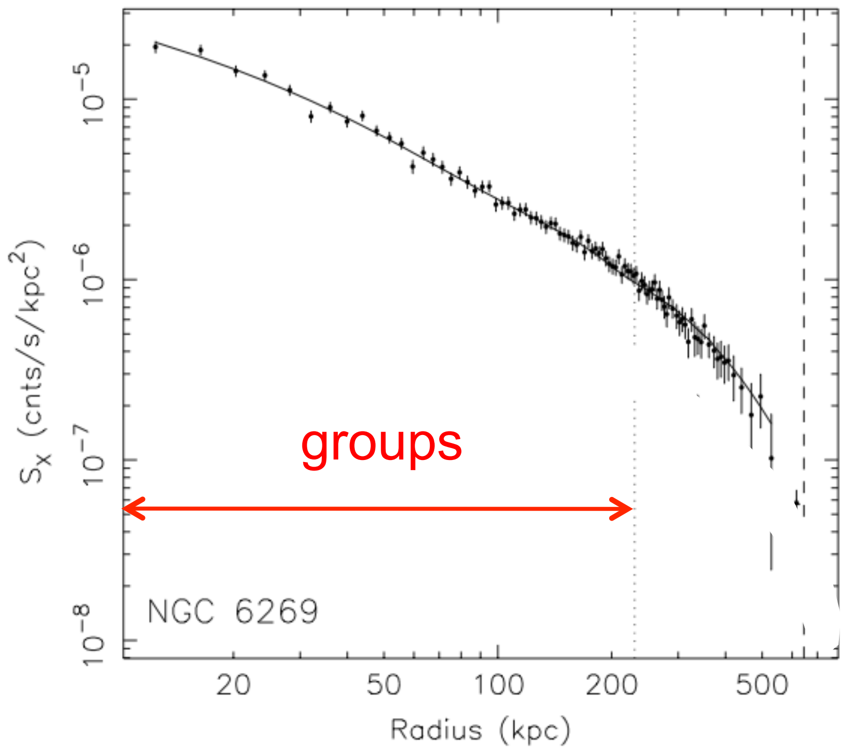
Mass vs Temp calibration



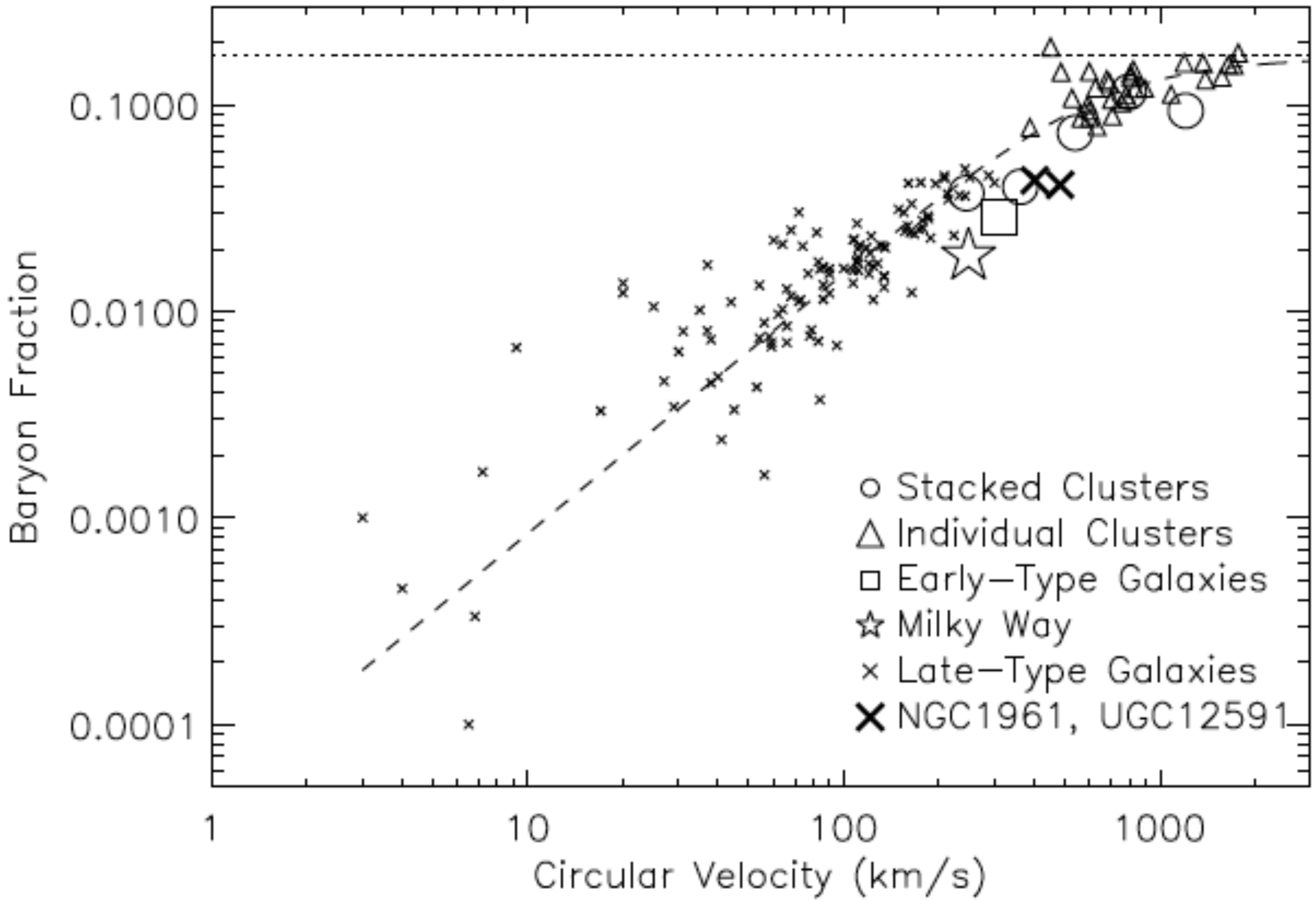
Baryon fractions in groups & clusters





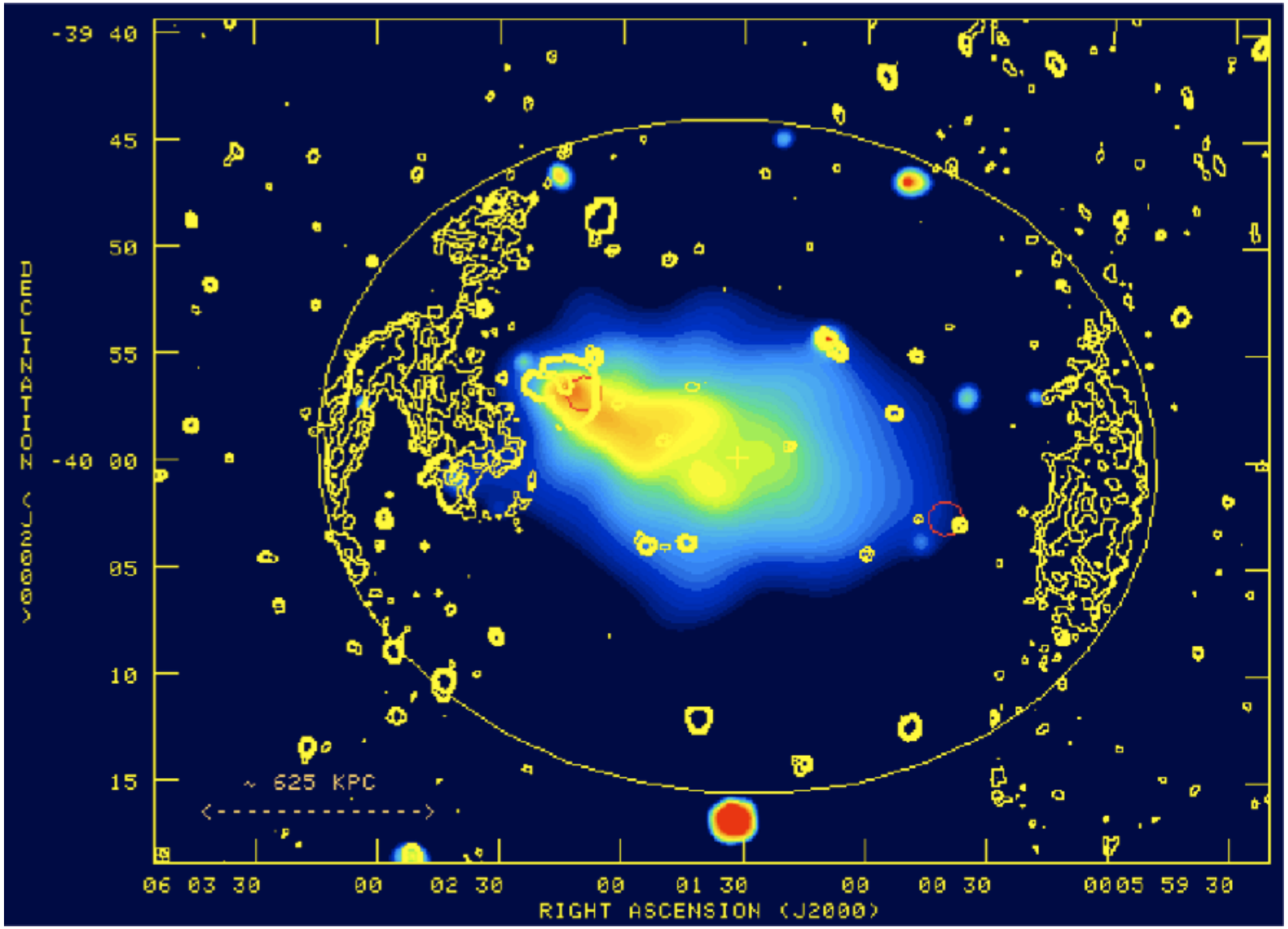


Baryon fractions down to galaxy masses



Dai+ 2012

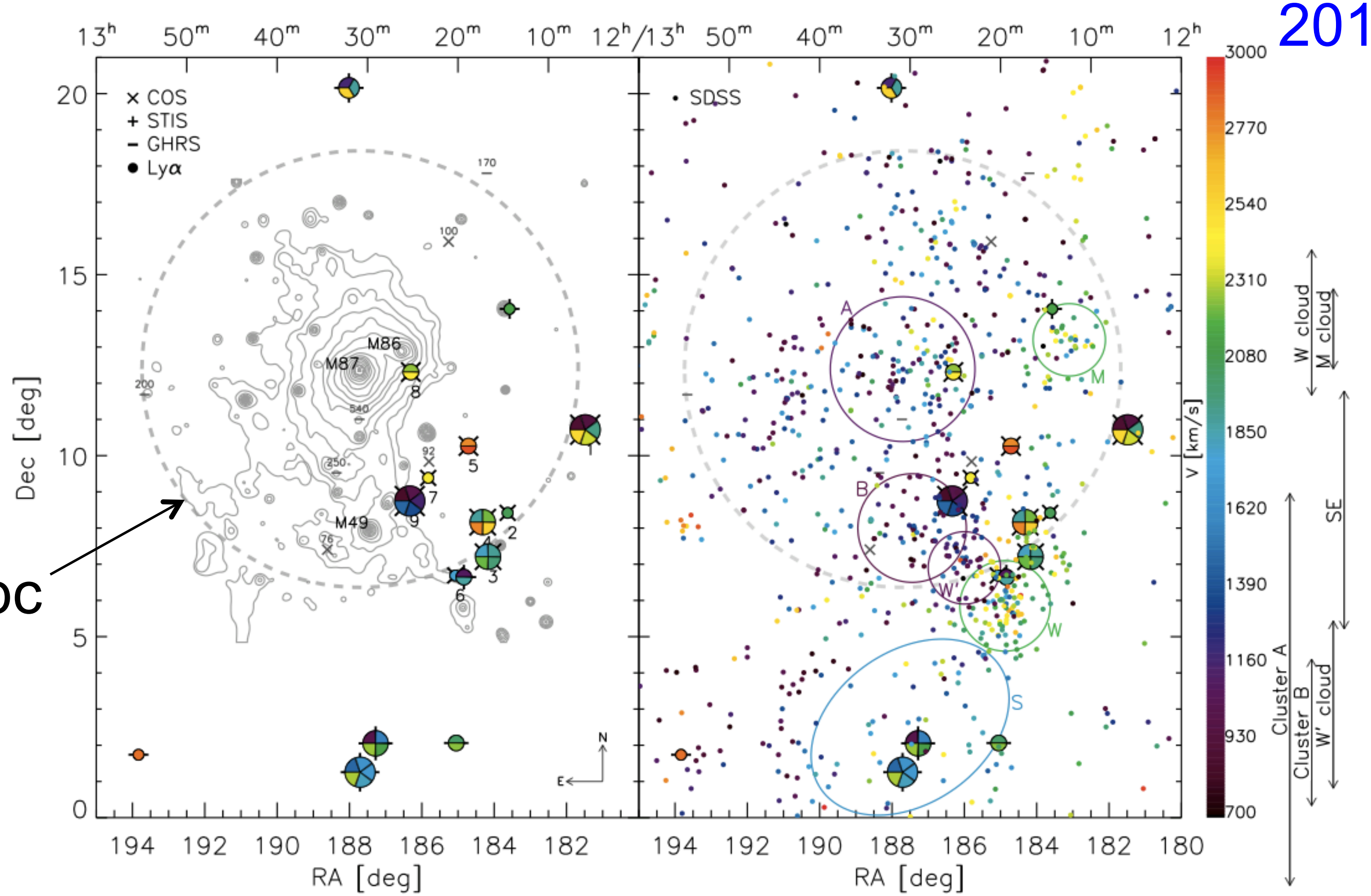
Large-scale shocks associated with accretion onto A3376



WARM GAS IN THE VIRGO CLUSTER: I. DISTRIBUTION OF Lyα ABSORBERS

JOO HEON YOON[1]*, MARY E. PUTMAN[1], CHRISTOPHER THOM[2], HSIAO-WEN CHEN[3], GREG L. BRYAN[1]

2012



R_{vir}=1.6 Mpc

The first systematic survey has found warm gas at the outskirts of the Virgo cluster (100%; $N_{HI} > 10^{13}$ cm^{-2}) – circumcluster medium ?

The intergalactic medium:
sheets, filaments & voids

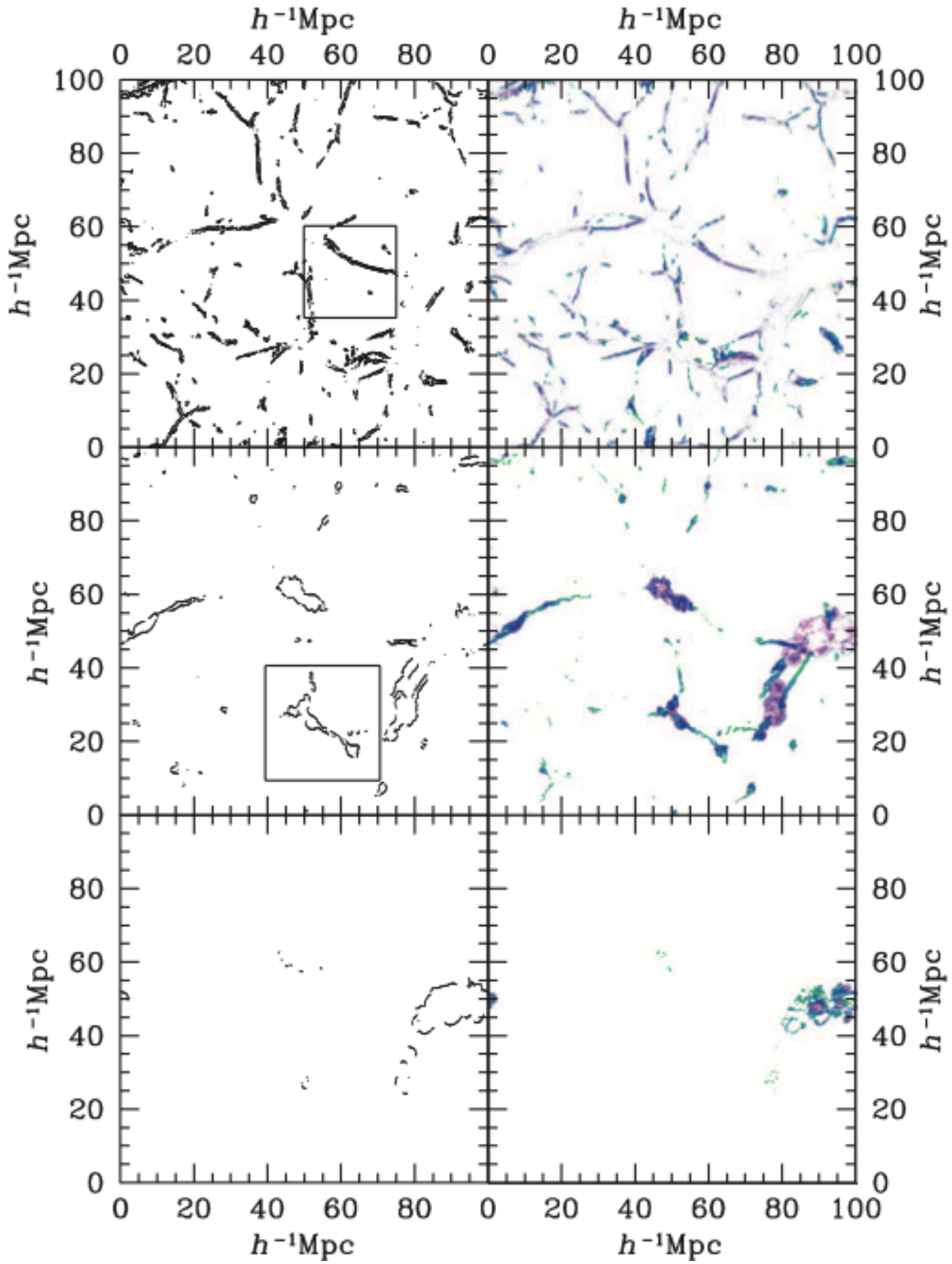
WHIM: large-scale shocks

$v_s < 150$ km s^{-1}

$T_s < 10^5$ K

$v_s > 700$ km s^{-1}

$T_s > 10^7$ K



Kang+ 2005

collisionally ionized

Tripp+06,08
Danforth & Shull 05,08
Thom & Chen 08
really need e.g. Ne VIII

Richter+04,06
Lehner+06,07
broad Lyα absorbers

Tilton+12:
integrated to log N_H > 12.5
rises to 31% if down to 12.0

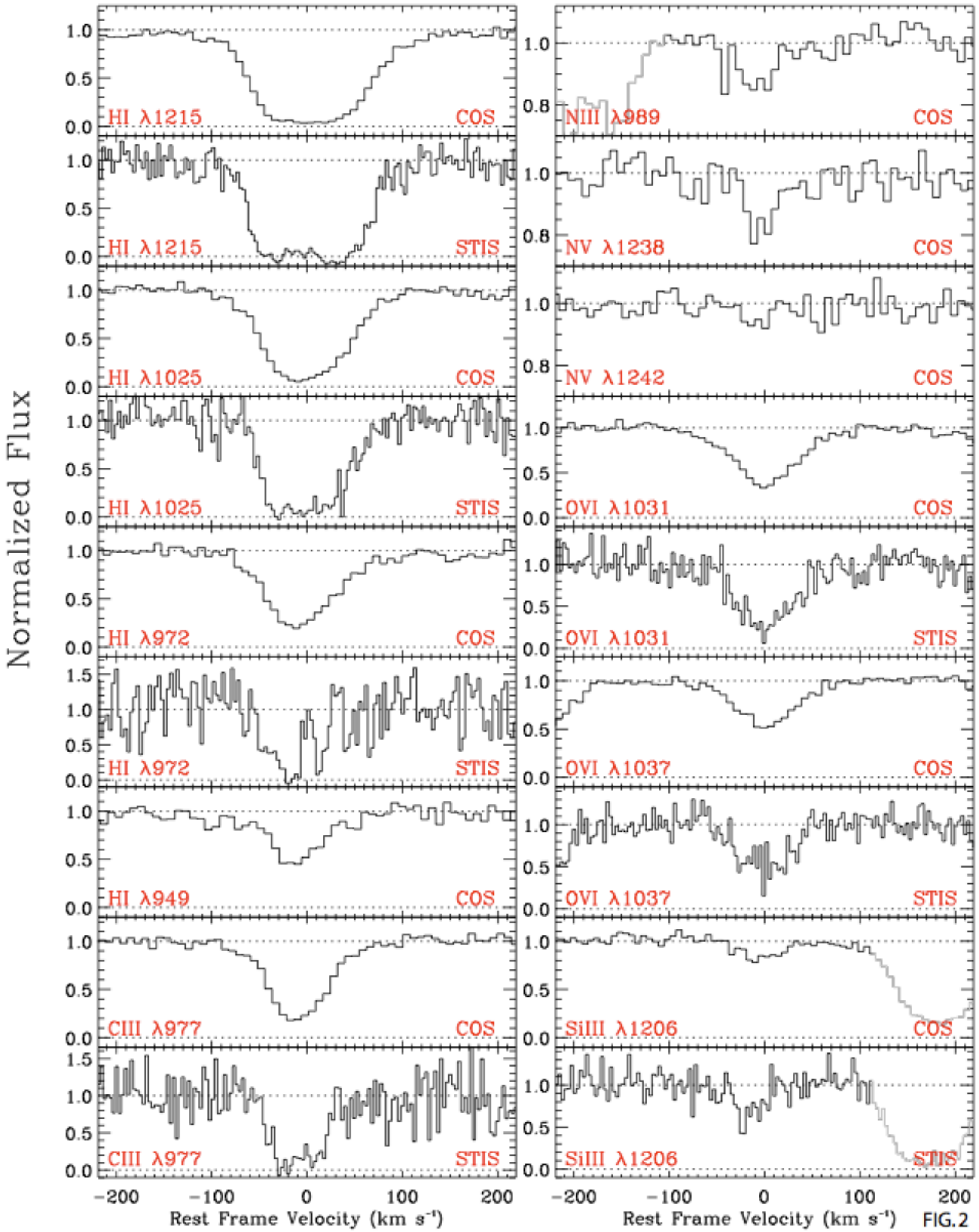
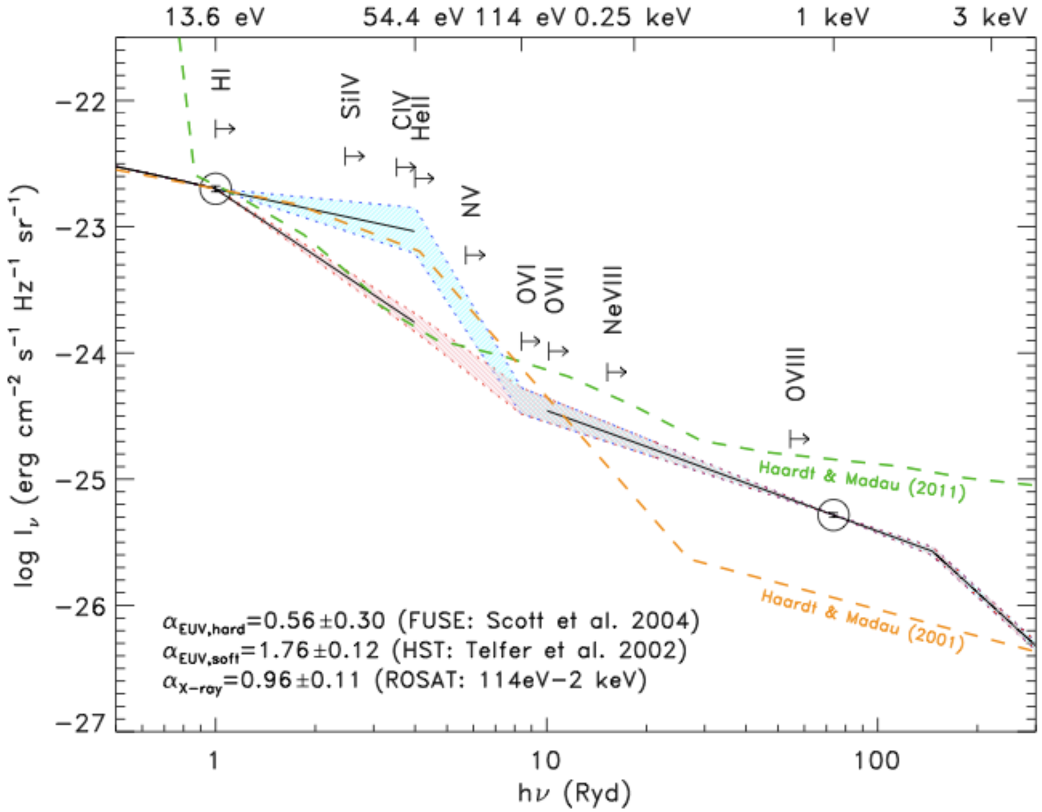


FIG.2

alaxies
7 ±2%
5 ±3%
5%
7 ±0.4

energy bands & diagnostics



shull+12

The way forward

The way forward –

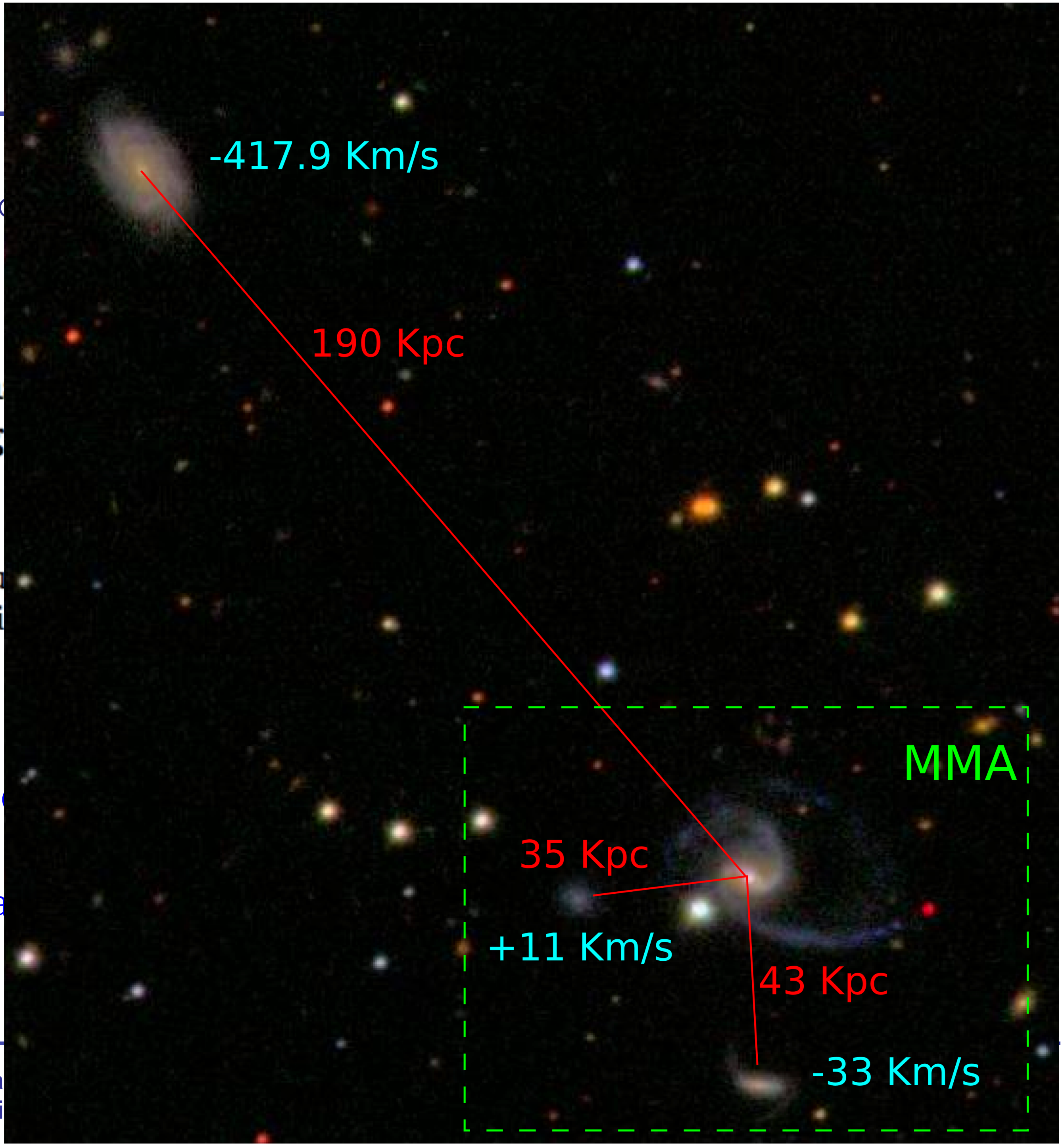
QSOs behind MW analo

Galaxy And Ma
Milky-Way Mag

A.S.G. Robotham[1,2*],
P. Norberg[6], A.E. Bau
A.M. Hopkins[7], S. Phi

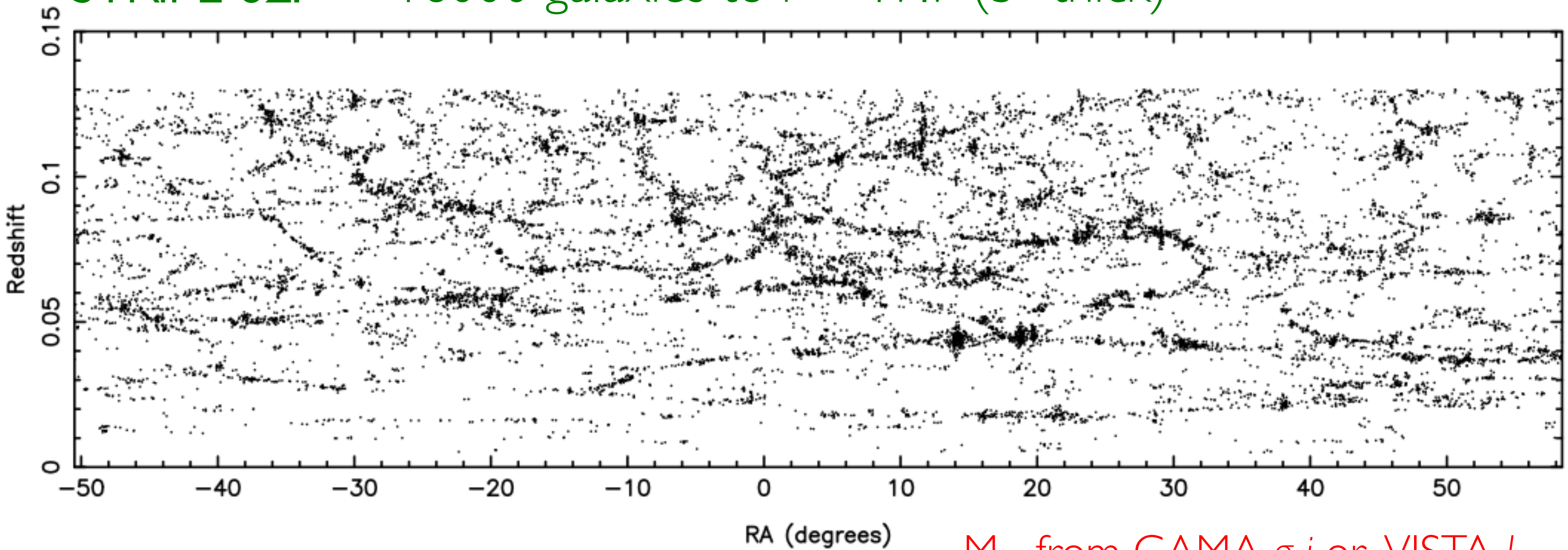
MWA (+LMC)
MWA (+LMC+SM

Interestingly, most a



Filaments in voids are now seen in redshift surveys

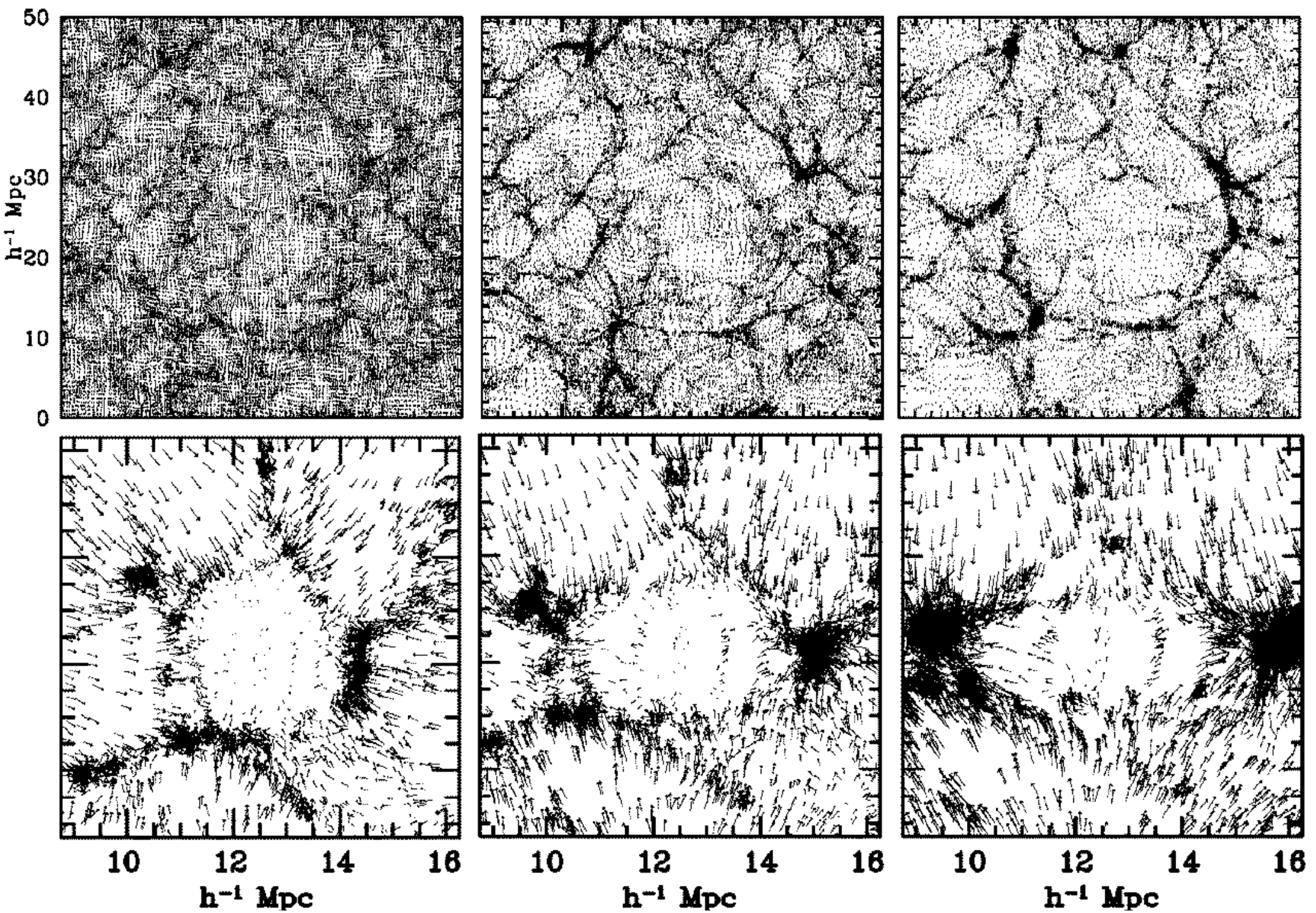
STRIPE 82: 16000 galaxies to r ~ 17.7 (3° thick)



$M_\star$ from GAMA *g-i* or VISTA *J*

Filaments in voids (**∇.v > 0**) are expected to be physically distinct from filaments in dense regions (**∇.v < 0**)

How does gas move out of voids?



Sheth & van de Weygaert 2004

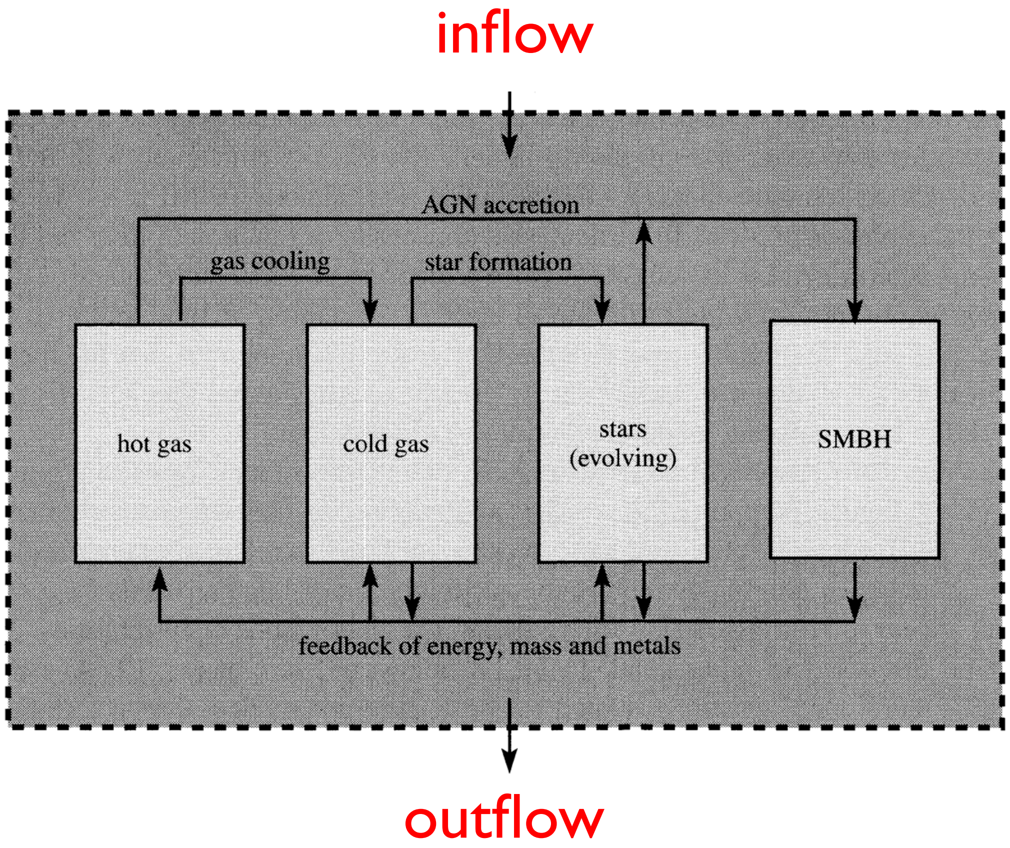
How do galaxies mess things up?

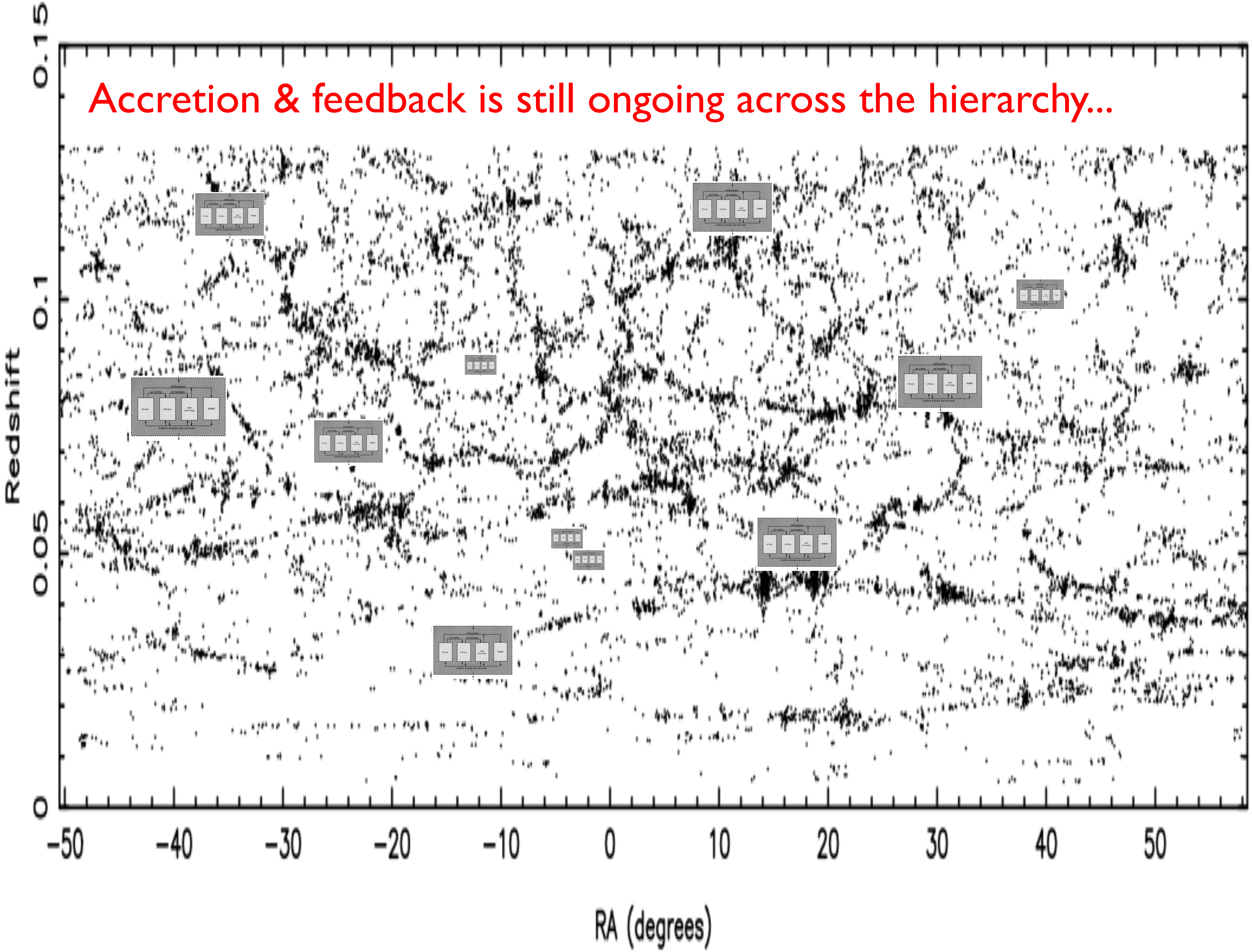
baryon fraction f_b

star formation history b

metallicity yield Y_{eff}

structural properties




Accretion & feedback is still ongoing across the hierarchy...
Redshift
0
0.05
0.1
0.15
-50
-40
-30
-20
-10
0
10
20
30
40
50
RA (degrees)

Summary

15% baryons collapsed (GF is an inefficient & complex process);
85% baryons uncollapsed, half still missing.

We need to understand the physical state of each gas phase before talking about a complete inventory (e.g. CGM inflow? outflow?).

We know little about the dynamics of gas flows onto mass structures on any scale, although there may be some evidence that these processes are now being observed. **Most of the action was at high redshift but the same processes are still ongoing.**

We need targetted surveys, e.g. MWA, void filaments, differential analysis of inside/outside virial radii (galaxies, groups, clusters).