The Void Problem and an HI (wishful) Perspective on Minihalos

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The Void Problem

Scenario set by Peebles 2001:

–ΛCDM simulations show voids not being empty: they contain lower mass halos that *“seem to be capable of developing into observable void objects”*

-Observations, however, seem to indicate that the spatial distribution of dwarf galaxies is remarkably similar to that of brighter galaxies

➔ faint galaxies do not show a strong tendency to fill the voids, so…

with Snow White we ask

Where are the Dwarfs?

Disclaimer: this is NOT part of Jim Peebles’ paper

The Void Problem rationale:

• Since voids have densities ~1/10 of the mean and they occupy a large volume fraction, lots of void objects should be observed.

• At high z, the density of regions that eventually will develop into voids is not very different from the average. Hence, fluctuations should grow and halos form. The number of collapsed halos per comoving volume should be ~preserved.

• *The key assumption, in saying that there is a "Void Problem", is that ΛCDM predicts the existence of many more dwarf galaxies than observed. Does it?*

A little about observations…

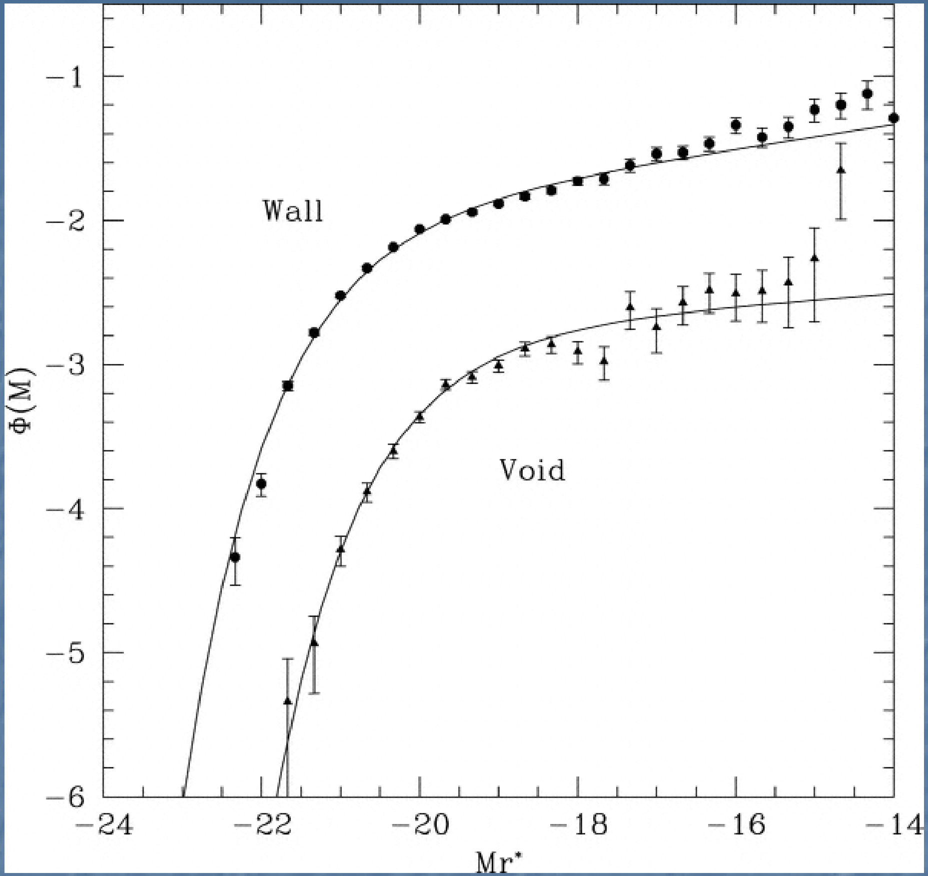
Hoyle et al. (2005) used a NN3 to extract a sample of 1010 "void" galaxies, defined as objects residing in regions with on scale of 10 Mpc, and a sample of 12732 "wall" galaxies, from SDSS DR1-2.

Void LF:

$$\Phi^* = (0.19 \pm 0.04) \times 10^{-2} h^3 Mpc^{-3}$$
$$M_r^* - 5\log h = -19.74 \pm 0.11$$
$$\alpha = -1.18 \pm 0.13$$

Wall LF:

$$\Phi^* = (1.42 \pm 0.3) \times 10^{-2} h^3 Mpc^{-3}$$
$$M_r^* - 5\log h = -20.62 \pm 0.08$$
$$\alpha = -1.19 \pm 0.07$$



Hoyle et al. 2005

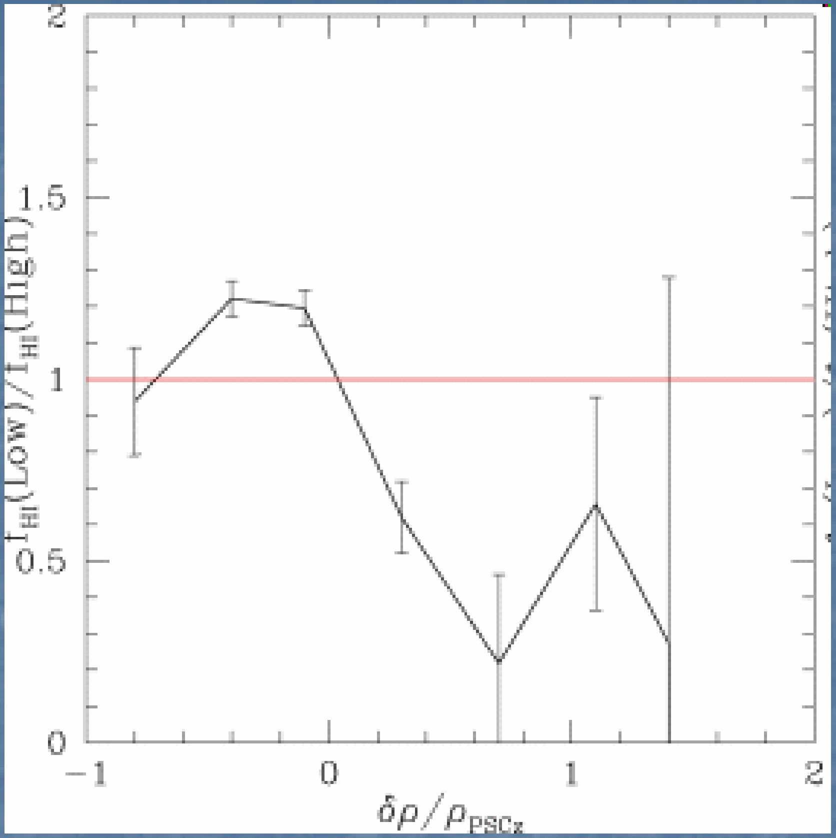
Void galaxies are typically fainter (M*) than Wall galaxies, but there is no significant excess of dwarfs (α) to populate the voids.

Within fixed luminosity bins, Void galaxies are also bluer, have smaller total stellar mass and higher SFR than Wall galaxies (Rojas et al. 2004, 2005)

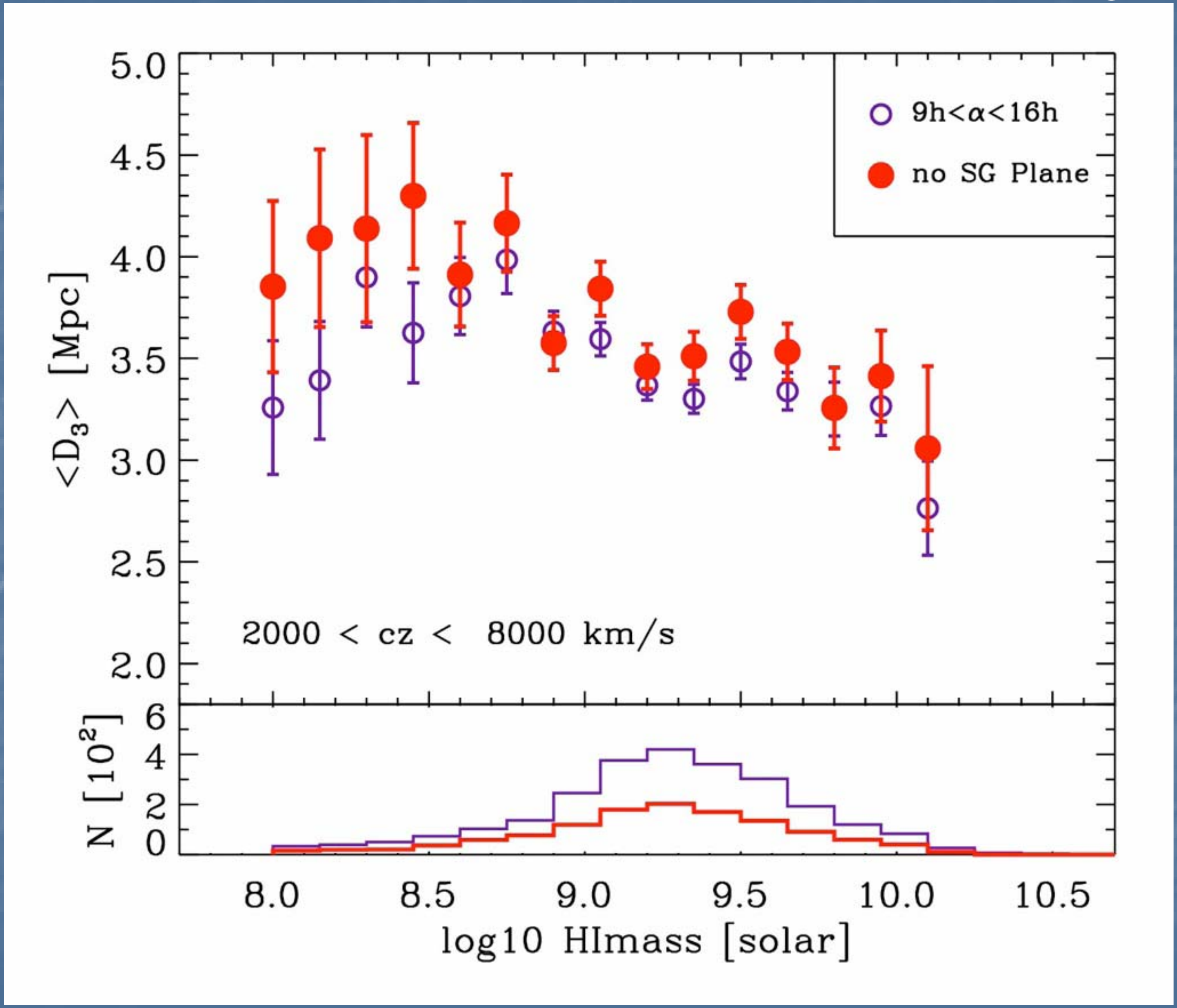
Basilakos et al (2007)

Using the results of HIPASS, they detect a marginal signal suggesting that low HI mass sources are more likely to inhabit low density regions than high HI mass sources.

They propose that low mass HI galaxies “*could be the typical population of galaxies in void-like regions*”.



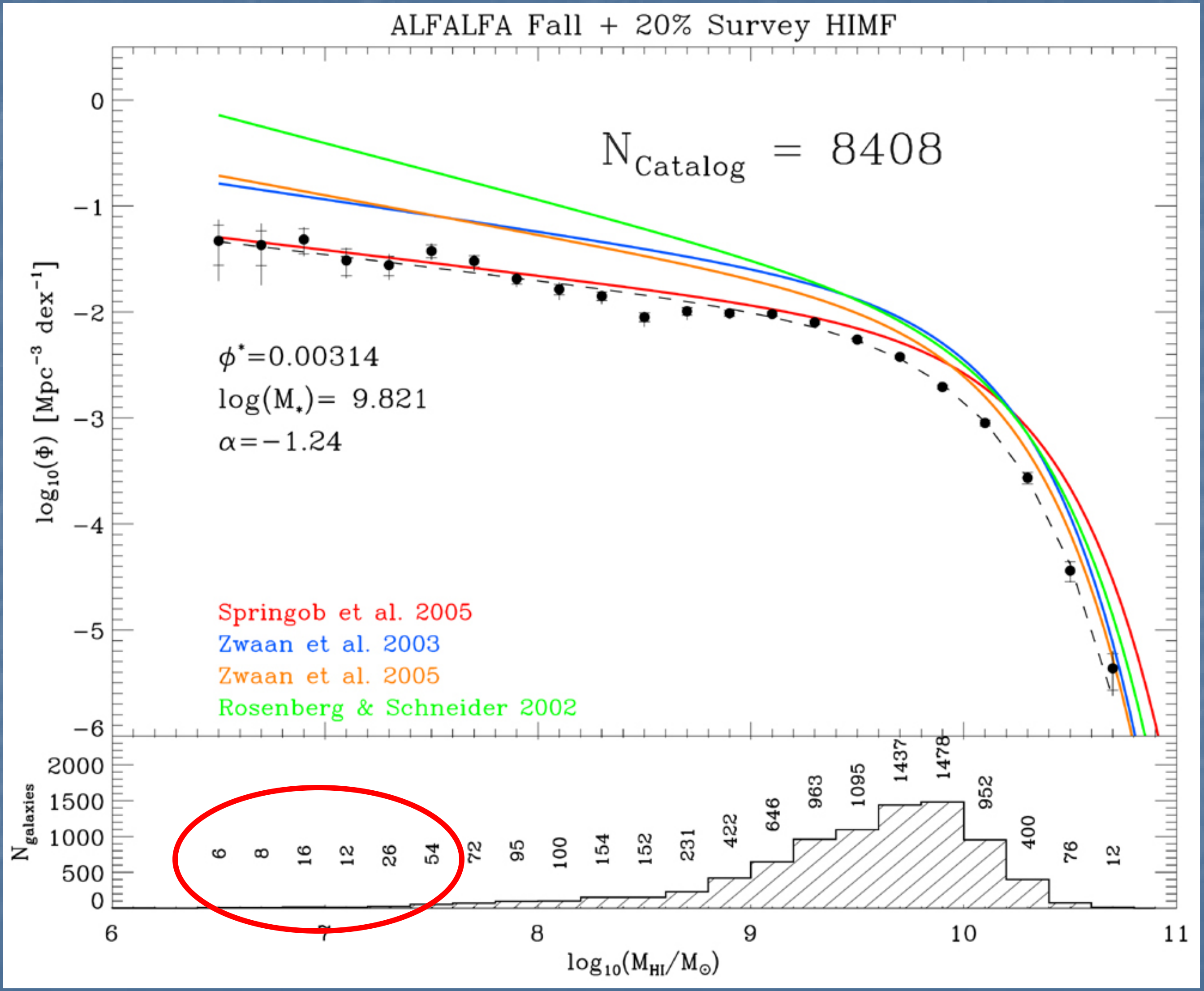
ALFALFA HI sources – Mean distance to 3d nearest neighbor



Within the pop. of gas-rich systems, lower HI mass systems tend to favor inhabiting the lower density regions.

Amelie Saintonge, 2009 in preparation

ALFALFA HI Mass Function



No overabundance of faint, HI-rich galaxies to fill the voids

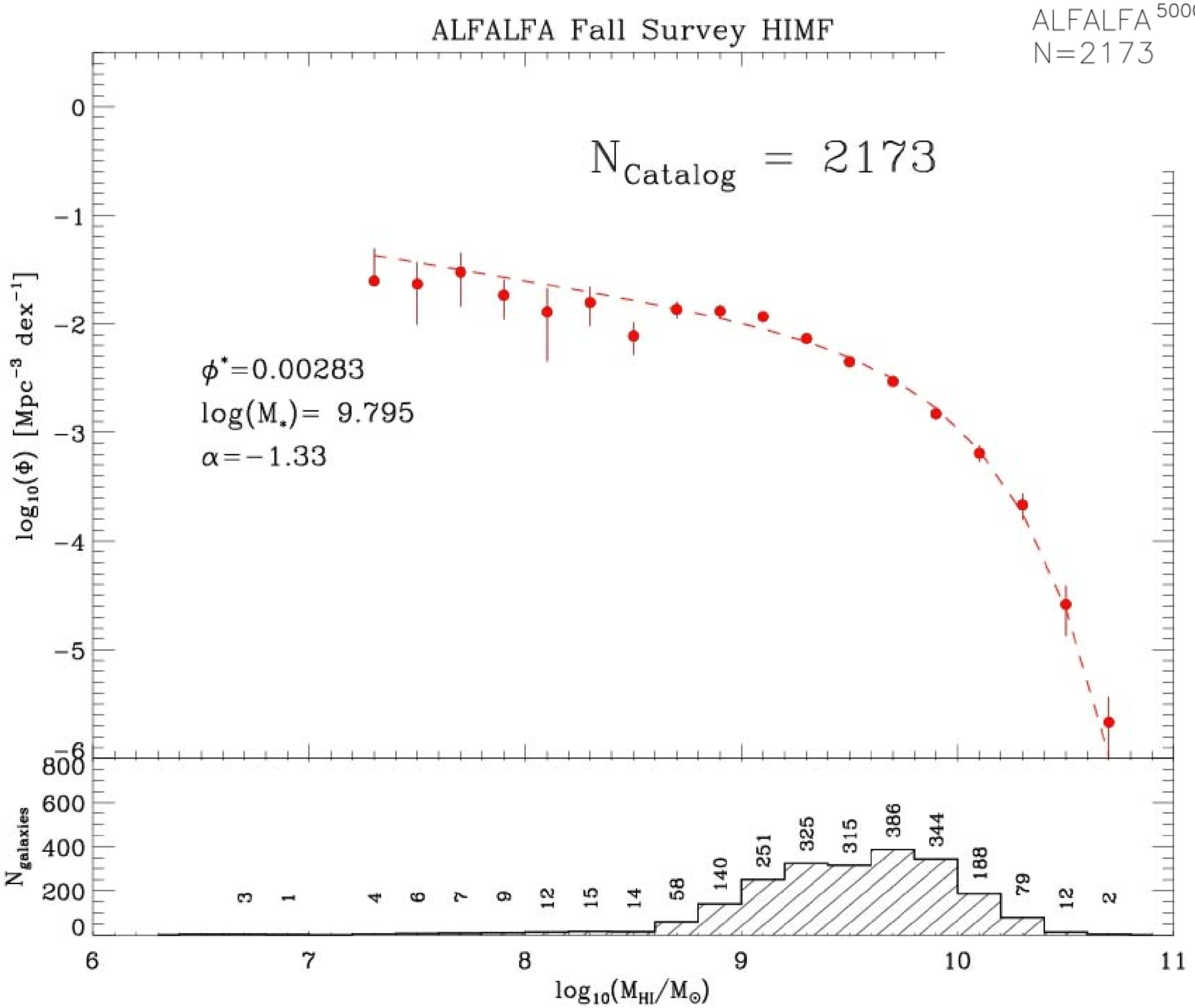
The Zwaan et al. 2003 HIMF, based on HIPASS, includes *12* galaxies with

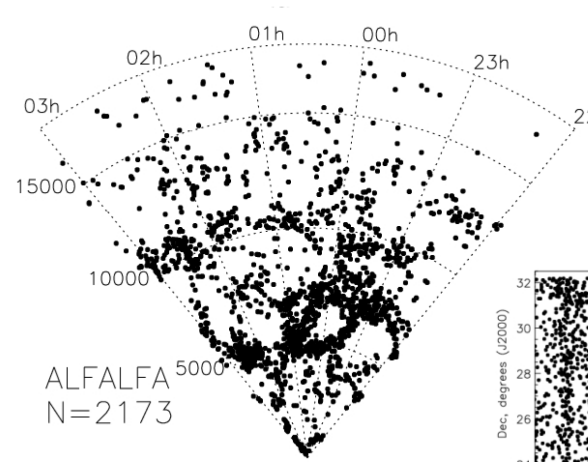
log M_HI < 7.5

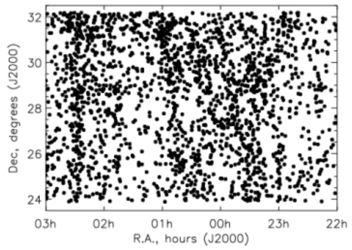
With <1/4 of ALFALFA processed, we have *122*

Ann Martin 2009, in preparation

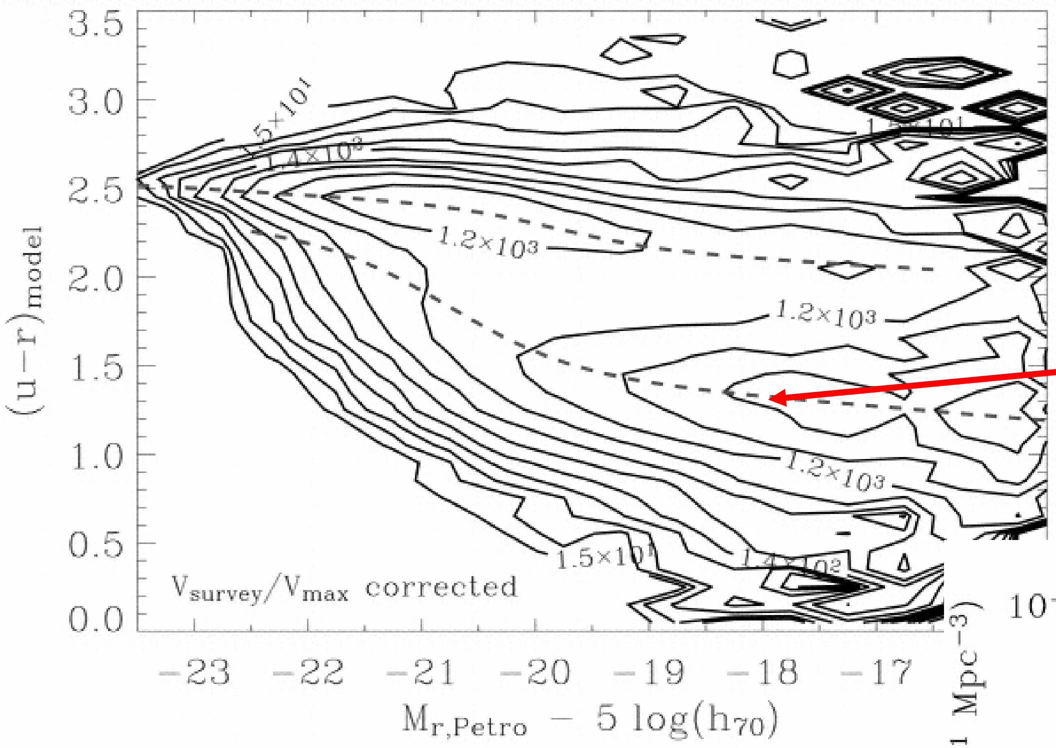
ALFALFA HIMF: Cosmic Variance Test





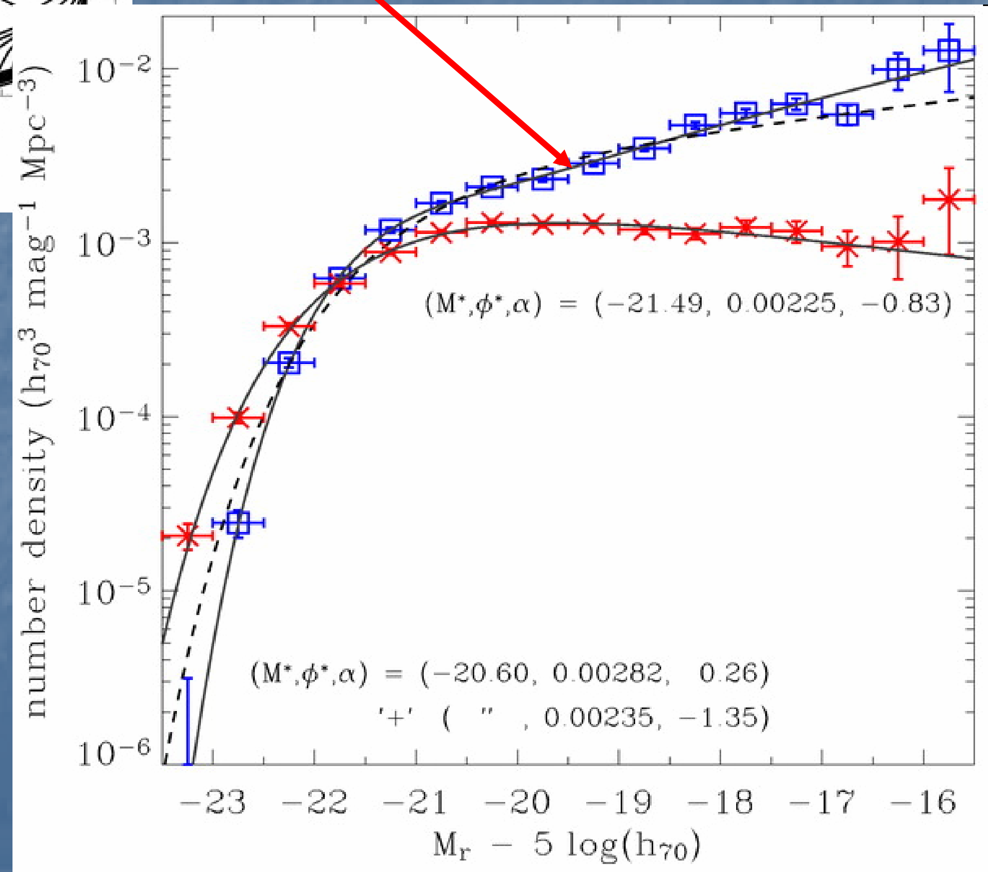


Ann Martin 2009, in prep.



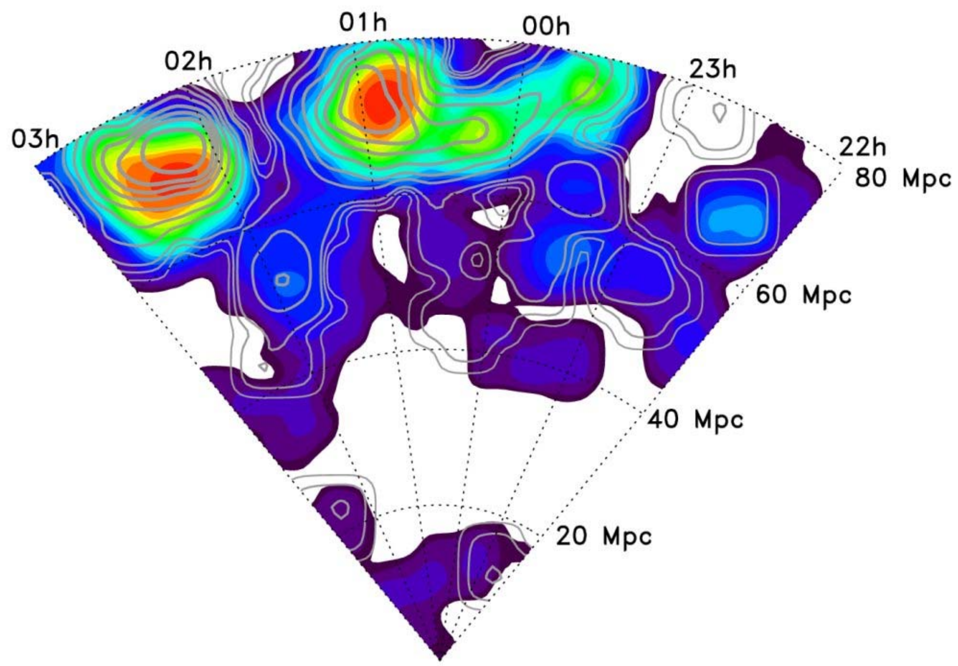
The faint end slope of the HI Mass Function is the same as that of the "Blue Cloud" galaxies of SDSS

Baldry et al. 2004



ALFALFA – PP Void
Decs 24 to 32 deg (22%)

Amelie Saintonge 2009, in preparation



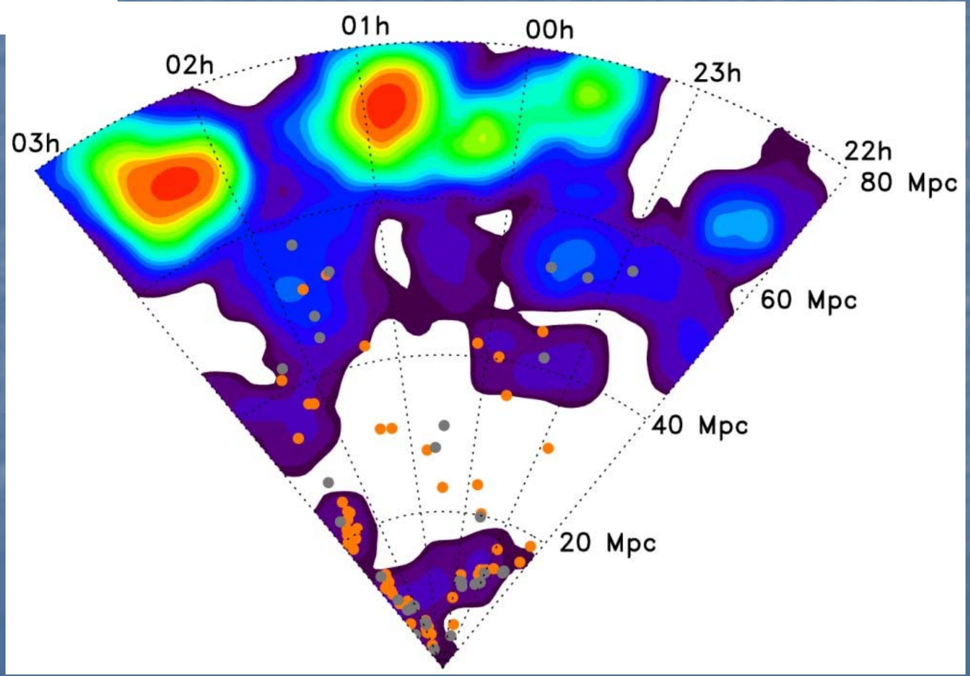
🡐Grey contours: optical volume limited at $M_B = -19.0$

🡐Color contours: HI volume limited at log(M_HI)= 9.2 solar

Grey dots: optical galaxies with $M_B > -18.$

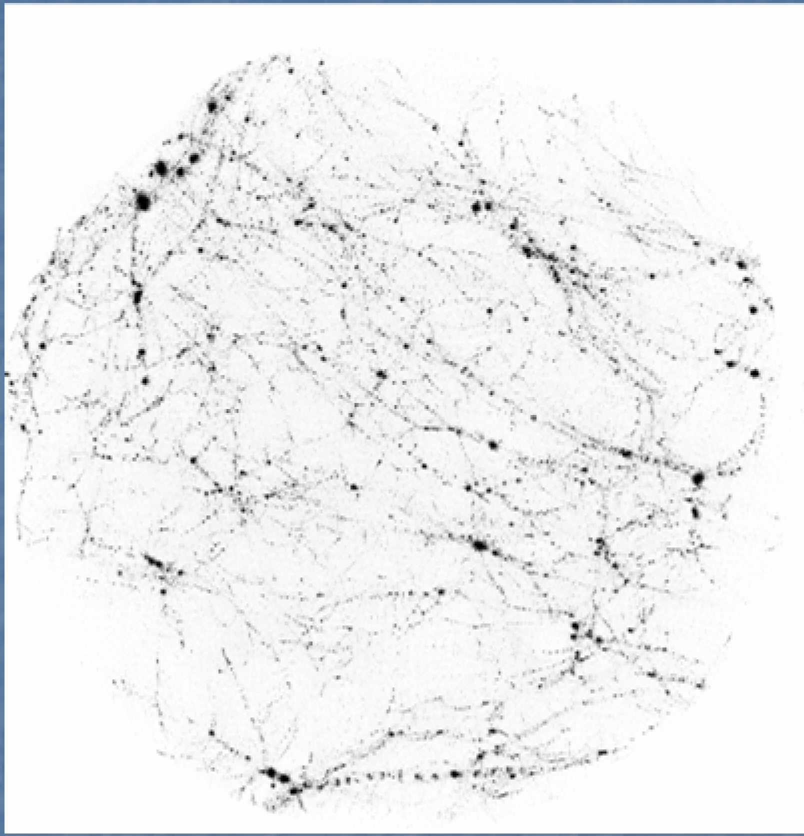
Orange dots: HI galaxies with log(M_HI) < 8. Msun

🡒



Voids: Simulations

Gottloeber et al (2003): DM in voids



- In a simulated volume of 120 Mpc, 20 voids with R>13 Mpc were identified, filling ~20% of the total volume. Such voids contain no halos with mass > 2.5×10^{11} Msun.
- The structure of the DM distribution in voids is similar to that seen in other density regimes: filaments, empty regions and concentrations where filaments cross. However, more massive "nodes" appear to prefer the outer parts of the voids and their masses are scaled down by a few orders of magnitude – so that the "nodes" correspond to the halo mass of a L<L* galaxy, rather than a cluster.
- The edges of voids outlined by the most massive halos (M~10^{12} Msun) are almost the same as those outlined by lower mass halos. The "typical" void dweller <u>is a halo of 1-2x10^9 Msun</u>.

Voids: Simulations

Gottloeber et al (2003): DM in voids

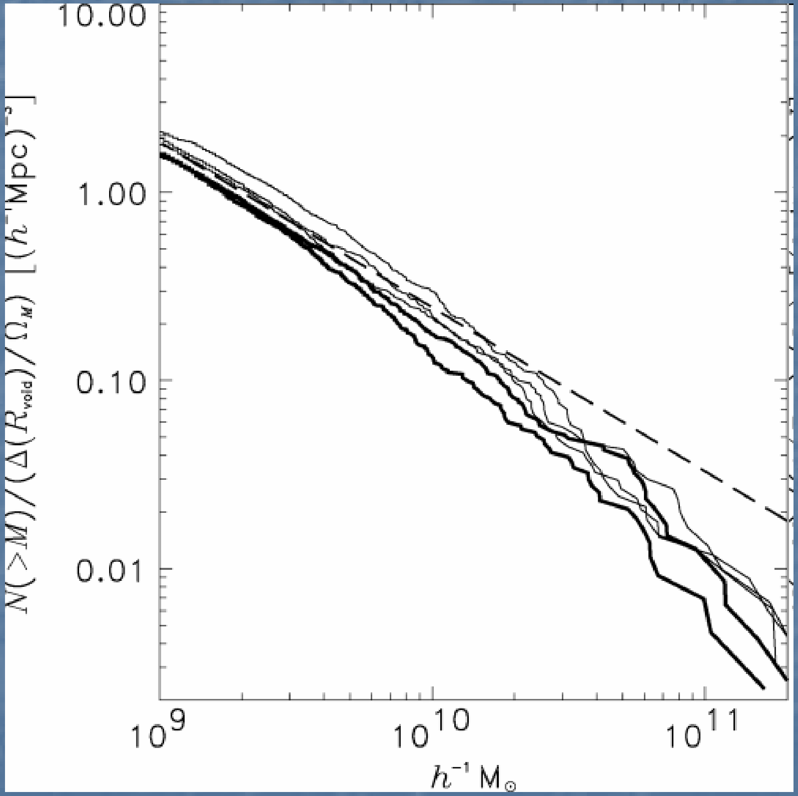
• The void halo mass function is steeper on the high end than that of galaxies in other density regimes; more massive halos are deficient in voids.

• The five largest voids in the simulation have avg. radius of ~14 Mpc. Inside one of such voids, about

➔ ~50 halos with V_c> 50 km/s (M>1.4x10^{10} Msun)

➔ ~1000 halos with V_c >20 km/s (M>1.4x10^9 Msun)

* Assuming that a galaxy of M =-16.5 inhabits a halo of 5x10^{10} Msun, the expected avg. number of galaxies brighter than -16.5 in a void of 14 Mpc radius is ~5.



Assembly Bias

*Gao, Springel & White (2005) found that the clustering properties of DM halos can depend strongly on their formation redshift (= by *which half of its z=0 mass was assembled*)

• Wechsler et al (2006) showed that halo concentration and subhalo occupation number et al are strongly correlated with formation redshift.

• Croton, Gao & White (2007) report that the clustering of DM halos depends not only on their mass but also on their assembly history

➔ "*Assembly Bias*"

• How can Assembly Bias affect Void populations?

- Assembly bias is seen to be stronger in lower mass halos; since low mass halos form later in underdense regions, z-dependence of the background UV flux will impact differently gas accretion and SF processes, than it would in different cosmic density regimes. Also note that the IGM density will presumably be lower in voids, which will affect the gas accretion rate by galaxies.

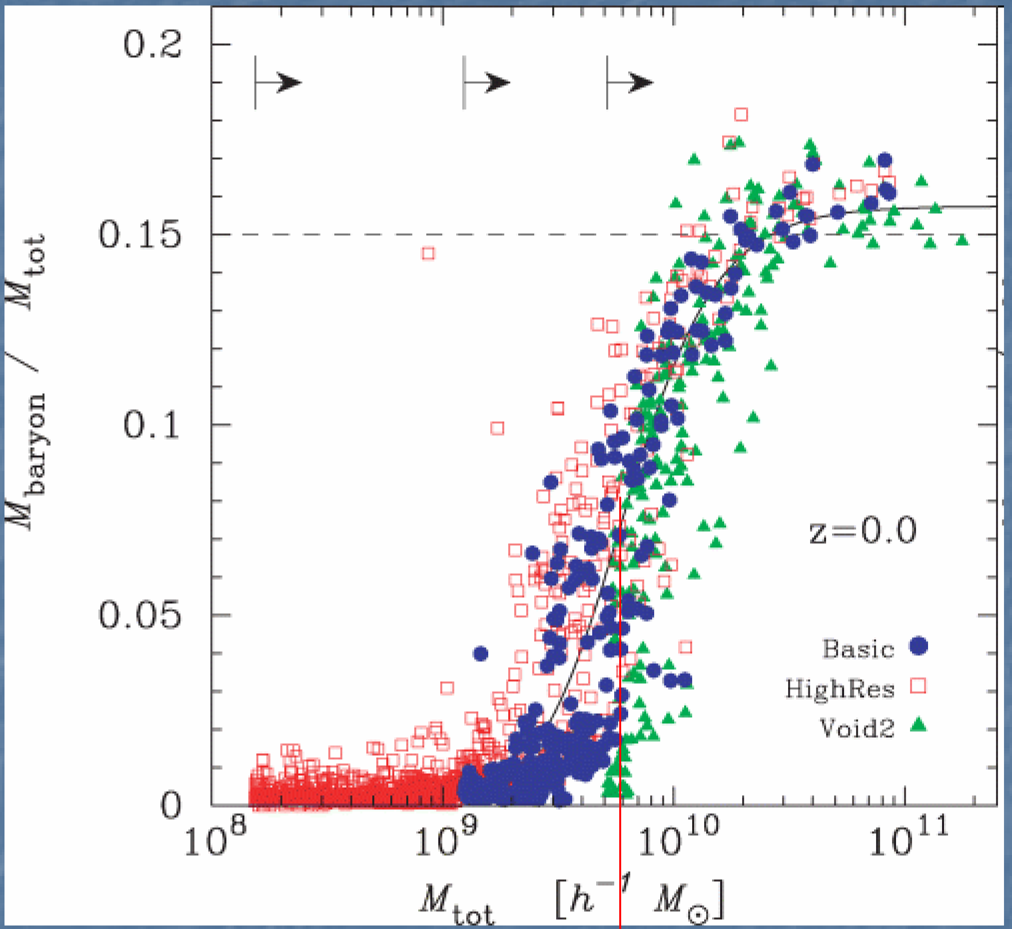
Simulations with Gastrophysics

-Hoeft et al. (2006) simulated the SF processes in voids, using code that included radiative processes, SN feedback and an external, photoionizing Hardt & Madau (1996) UV background, with a resolution that allows monitoring evolution of DM halos of mass as low as 2.3×10^8 Msun.

-As Gottloeber et al did before, they find voids filled with halos of $M<10^{10}$ Msun. <u>If each of those retained its share of the cosmic baryon fraction and converted it into stars without significant suppression of gas cooling, a high density of luminous dwarfs should be expected in dwarfs.</u>

- However, small halos DO NOT retain their share of baryons ➔

- Note dependence on simulation **resolution!**



Characteristic halo Mass M_c : that which retains 50% of its baryons

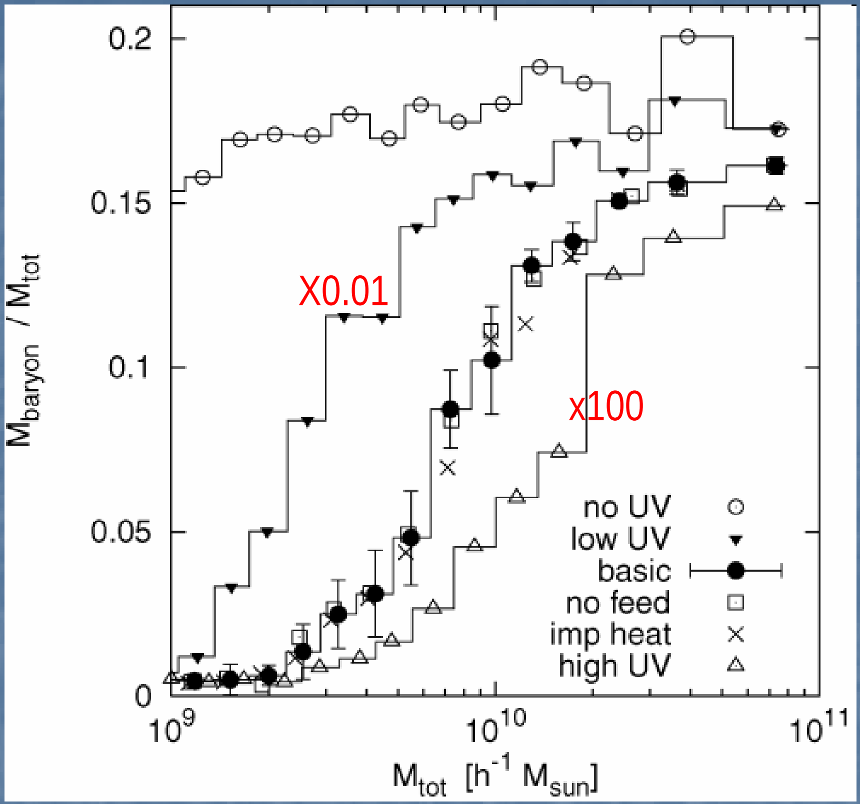
-Hoeft et al 2006 (cont.):

-The retained baryon fraction depends on the UV background flux ➔
(low UV = x0.01 high UV = x100)

-The UV background heats the gas to ~10^4 K
-In order for the gas to be accreted, cool and form stars, the halo T_{vir} must be at least ~10^4 K:

T_{vir} ~ 10^4 K ➔ M_{halo}~$2x10^9$ Msun at z=0

In halos less massive than ^^, the baryons stay warm and are not accreted.



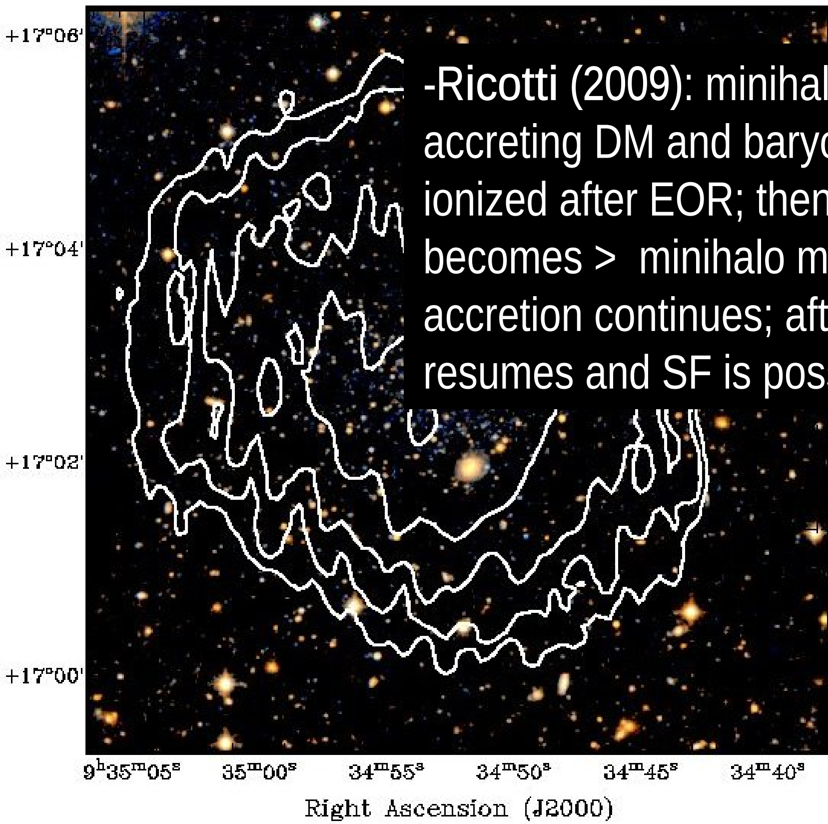
-But see: Sternberg, McKee & Wolfire (2002) coming up later…

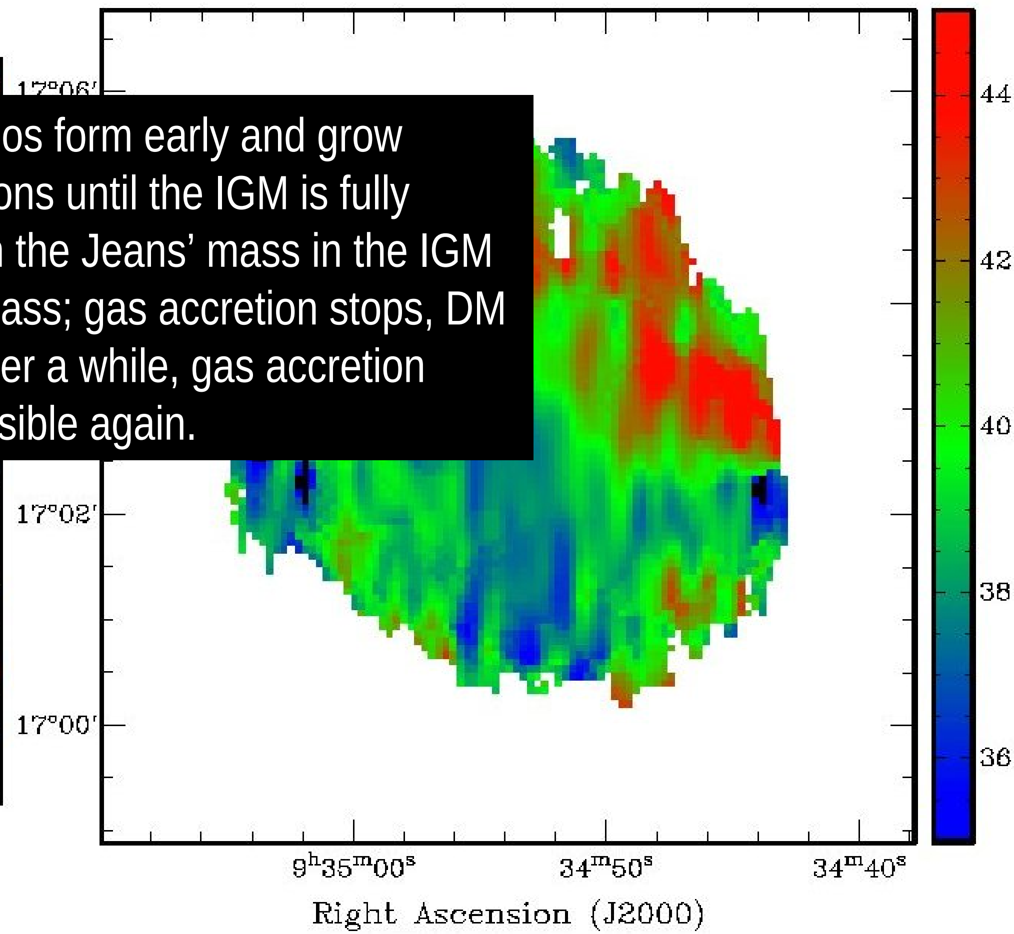
WSRT observations

- Nice, regular HI distribution. Some rotation???????
- H I velocity matches optical velocity: 39 vs 38 km s^{-1}
- Velocity dispersion H I: 7 km s^{-1}, stars 8 km s^{-1}
- M_{dyn}/L_V ~ 125

HI mass = 3x10^5 Msun
HIMass/L_V = 5
M_dyn=8x10^6 Msun
… and still forming stars…
[80% of visible baryons in HI]

Credit: T. Osterloo, Spineto 2007





-Ricotti (2009): minihalos form early and grow accreting DM and baryons until the IGM is fully ionized after EOR; then the Jeans' mass in the IGM becomes > minihalo mass; gas accretion stops, DM accretion continues; after a while, gas accretion resumes and SF is possible again.

contours 2, 5, 10, 20, 50 ·10^{19} cm^{-2}

Voids: Simulations

* *Halo Occupation Distribution (HOD)* is a technique used to interpret galaxy clustering. In populating halos with galaxies it assumes that the assembly history of a halo of given mass – and thus in delivering its galaxy content – is independent on the large-scale environment.

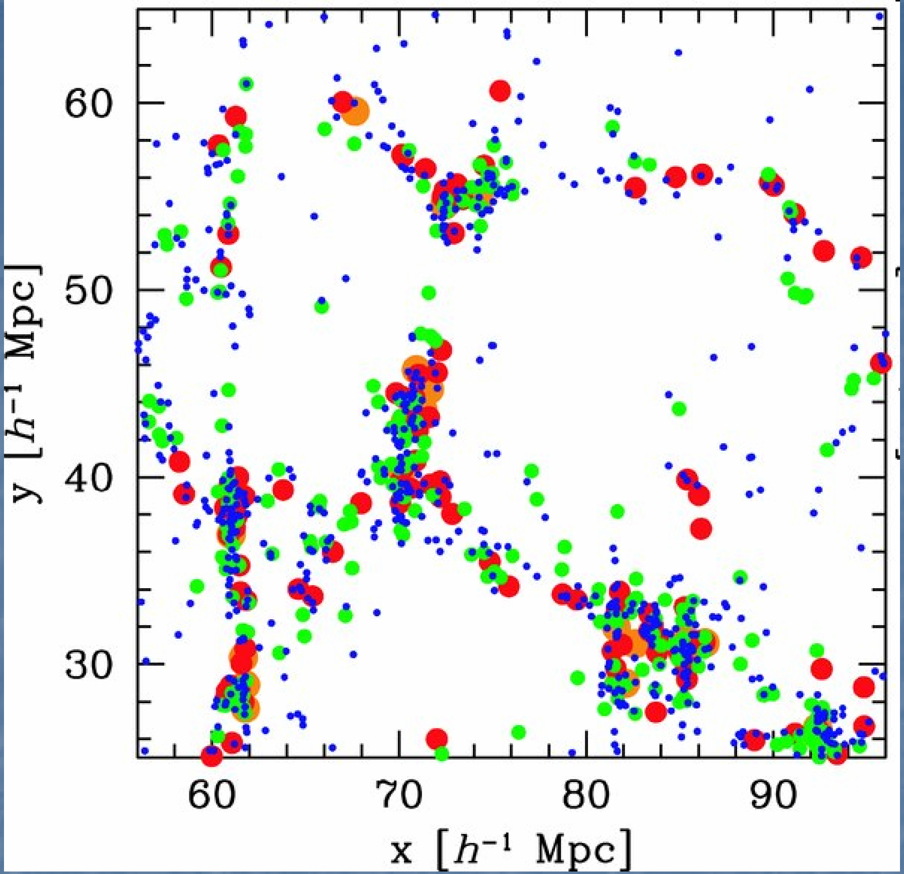
• Gao & White (2007) have shown how the Assembly Bias affects several characteristics of a halo: formation time, conncentration, subhalo mass fraction, spin. Assembly bias can therefore affect the predictions based on HOD, which assumes that a halo doesn't know whether it sits in a void or a filament, i.e. that its galaxy properties depend only on the halo mass.

However

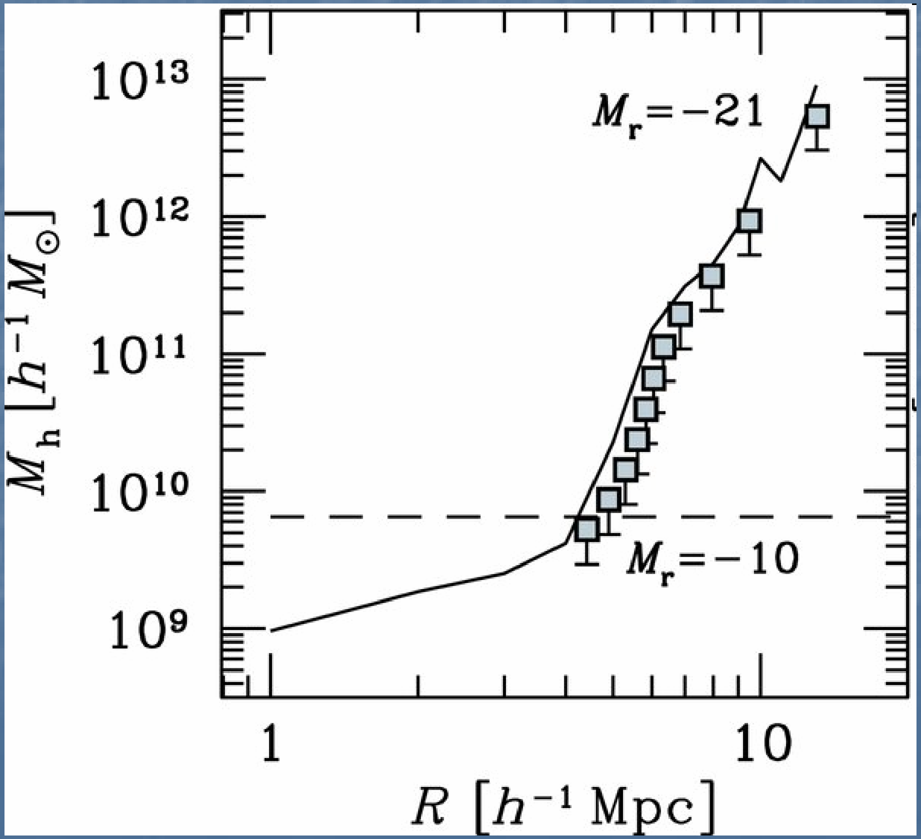
• Tinker et al. (2008) tested HOV and find that – at least for galaxies brighter than ~0.2L* - HOD is a satisfactory approach.

• Tinker & Conroy (2008) used HOD to show that there is no Void Problem.

Tinker & Conroy (2009) use a high resolution DM simulation, which they populate with galaxies via the HOD process. Galaxies of a wide range of L ~equally outline the voids ➔
[blue=-14/-15 green=-16/-17 red=-18/-19]



🡐Maximum halo mass found within distance R from center of void

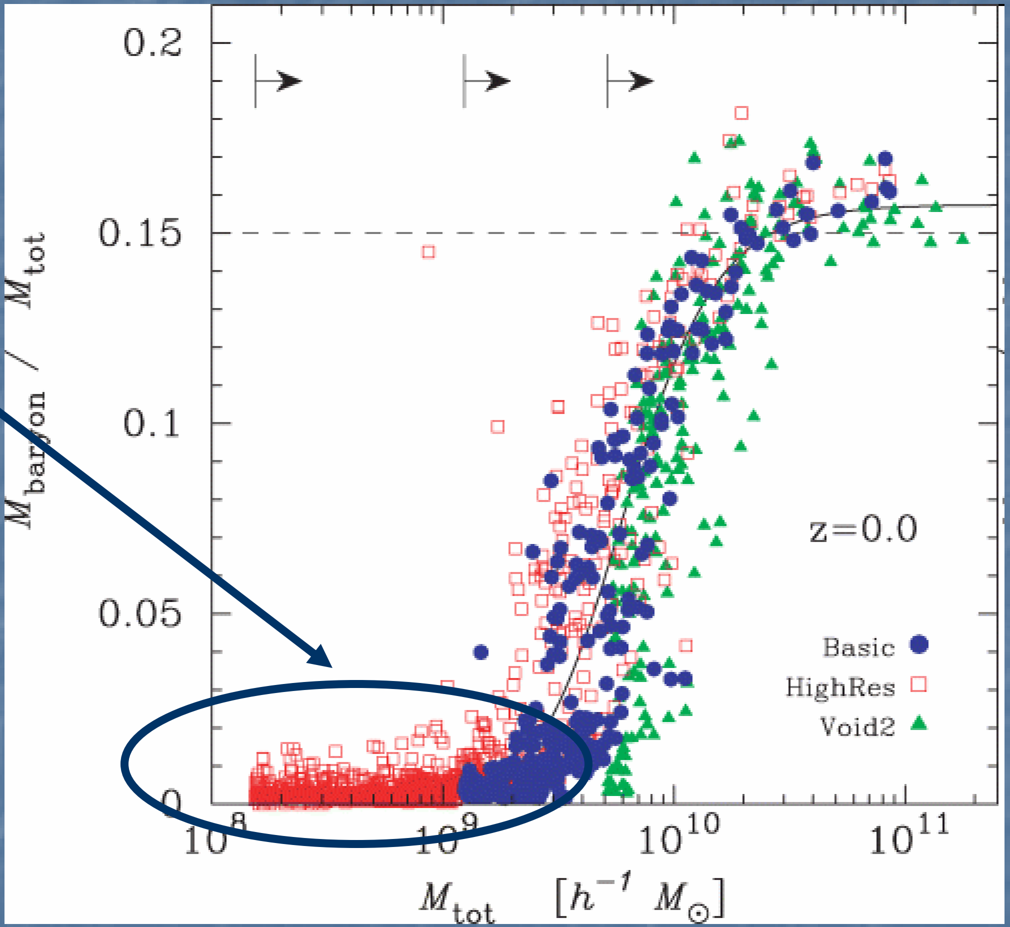


"Characteristic Mass" of Hoeft et al (2006):
=mass within which retained baryon fraction is ½ of cosmological value (0.16)

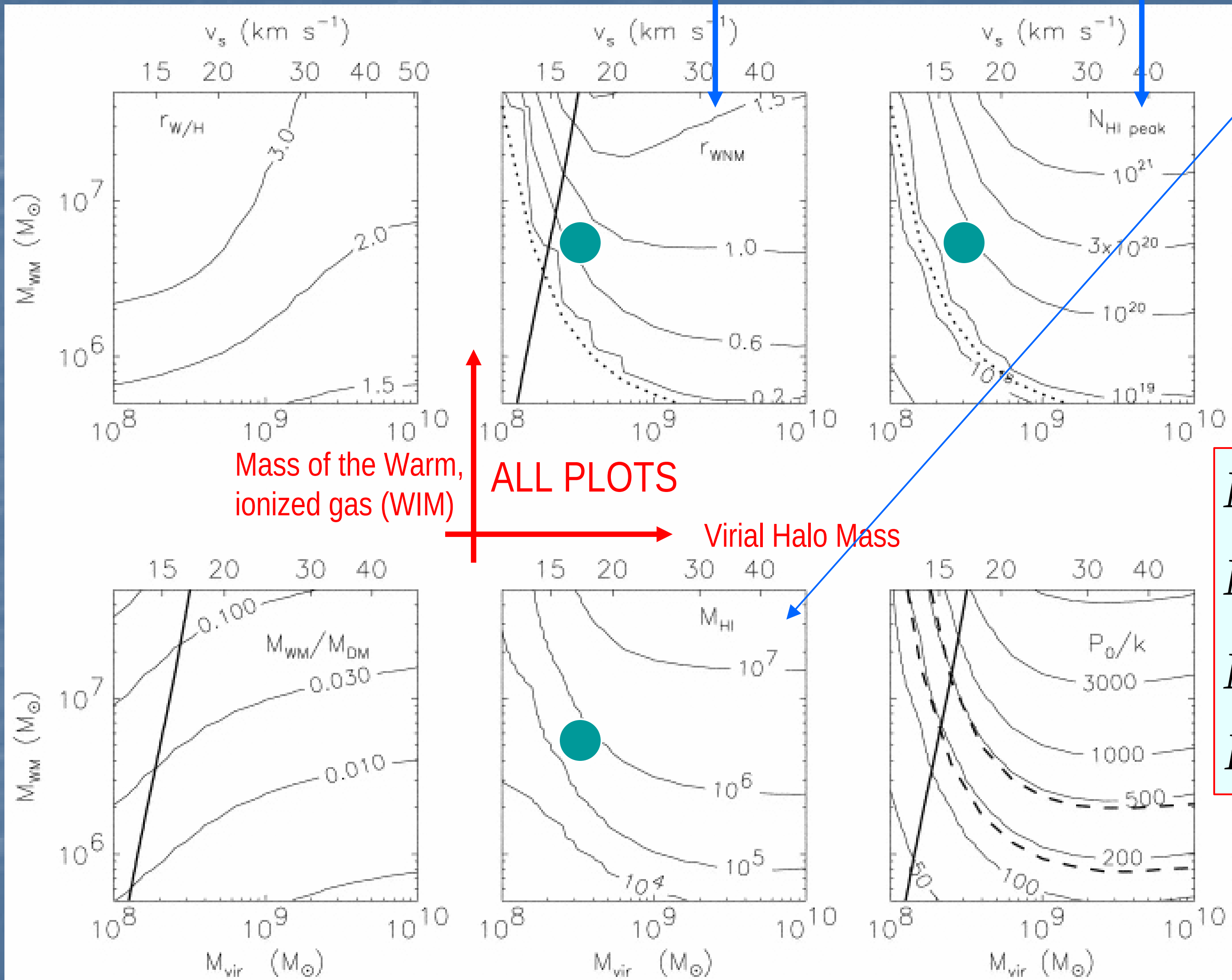
So is the "Void Problem" solved?

Do we have any chances to ever observe these guys?

Sternberg, McKee & Wolfire (2002) have investigated the gastrophysics of minihalos: the remaining baryons in a low mass halo are capable of developing a small WARM NEUTRAL phase (WNM), possibly detectable through its HI emission.



Contours of HI (WNM) radius (kpc) HI column density HI Mass



A possible model for a baryon-poor minihalo:

$$M_{halo} = 3\times10^8 M_{sun}$$

$$M_{baryon} = 5\times10^6 M_{sun}$$

$$M_{HI} = 3\times10^5 M_{sun}$$

$$R_{HI} = 0.7 kpc$$

Sternberg, McKee & Wolfire 2002

HVCs: an Intergalactic Population?

Blitz et al (1999): HVCs are large clouds, with typical diameters of 25 kpc, containing $3x10^7$ solar of neutral gas and $3x10^8$ solar of dark matter, falling towards [the barycenter of] the Local Group; altogether the HVCs contain 10^{10} solar of neutral gas."

Braun & Burton (1999): The "undisturbed minihalos appear as **Compact HVCs**, which have typical sizes of 0.5 deg and FWHM linewidts 20-40 km/s

Problems:

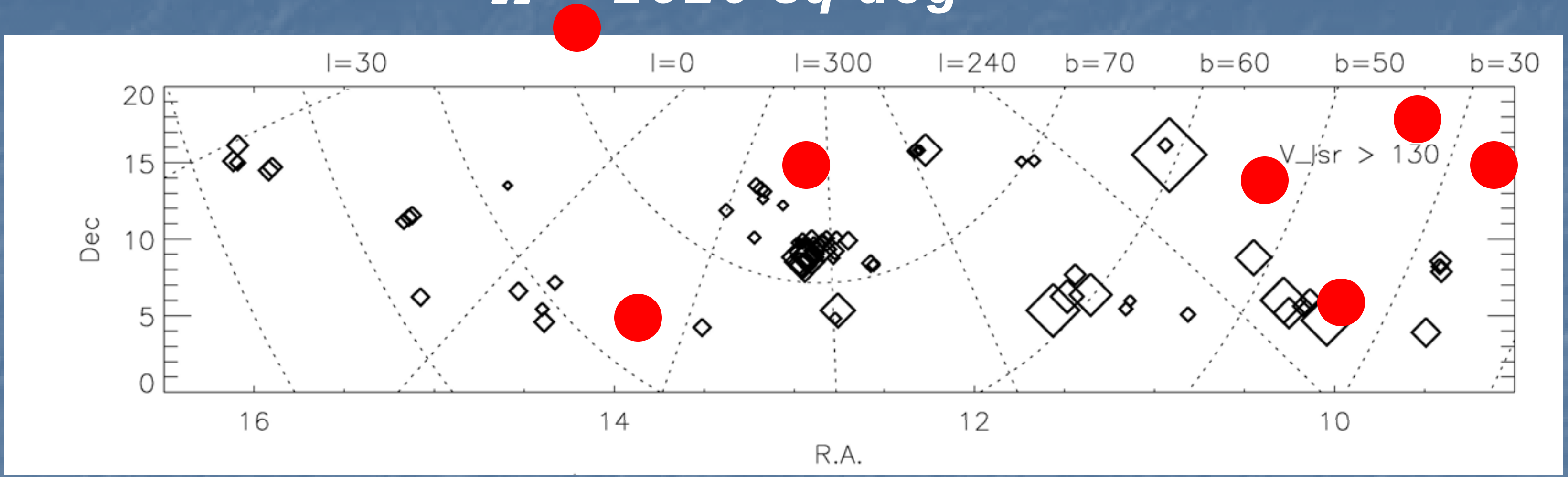
If HVCs (or CHVCs) are bona fide LG members, they should also exist in galaxy groups other than the LG: NOT SEEN

*2. **Sternberg et al (2002)** show that, in order to fit DM halo models to the CHVCs, their HI fluxes and angular sizes objects them to be <u>no farther than 150 kpc</u>, else they famously violate the ΛCDM mass-concentration relation: CHVCs ARE TOO LARGE*

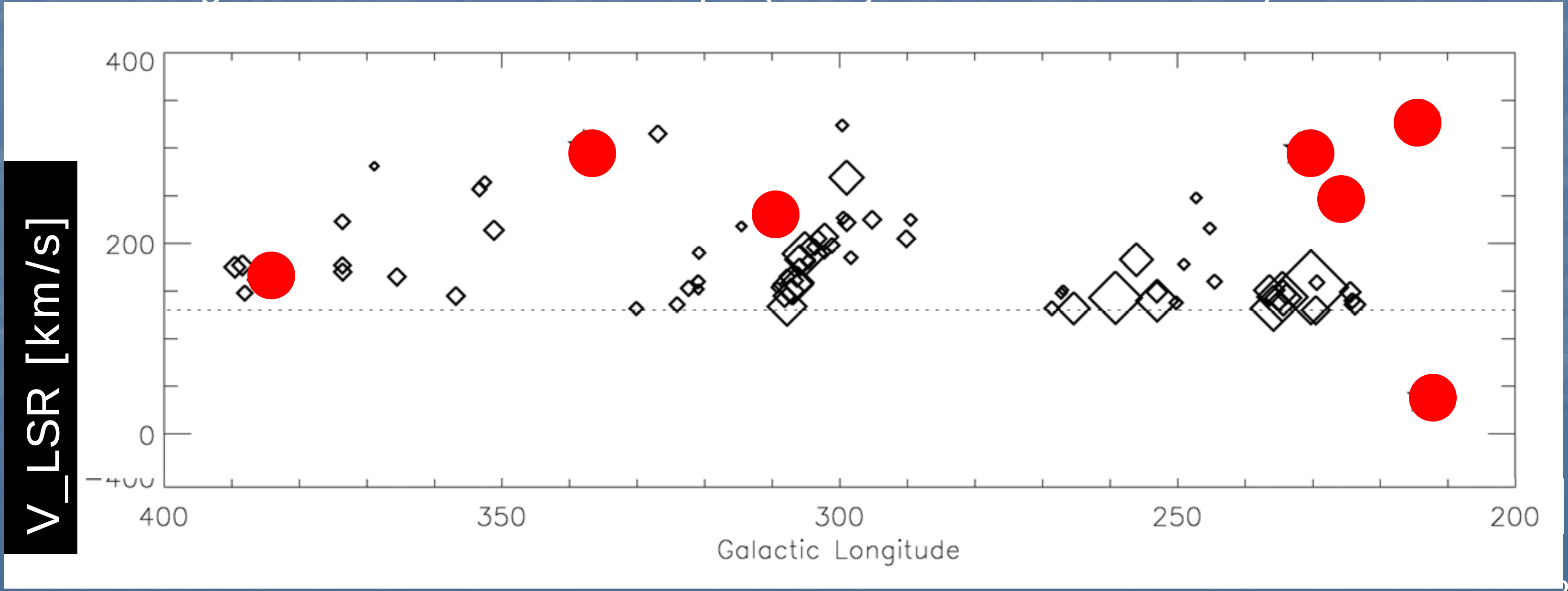
→ Enter ALFALFA

HVCs in footprint of ALFALFA, North Galactic Cap

Ω = 1620 sq deg



LG galaxies within D=2.6 Mpc (away from center of LG)



Karachentsev et al 2004

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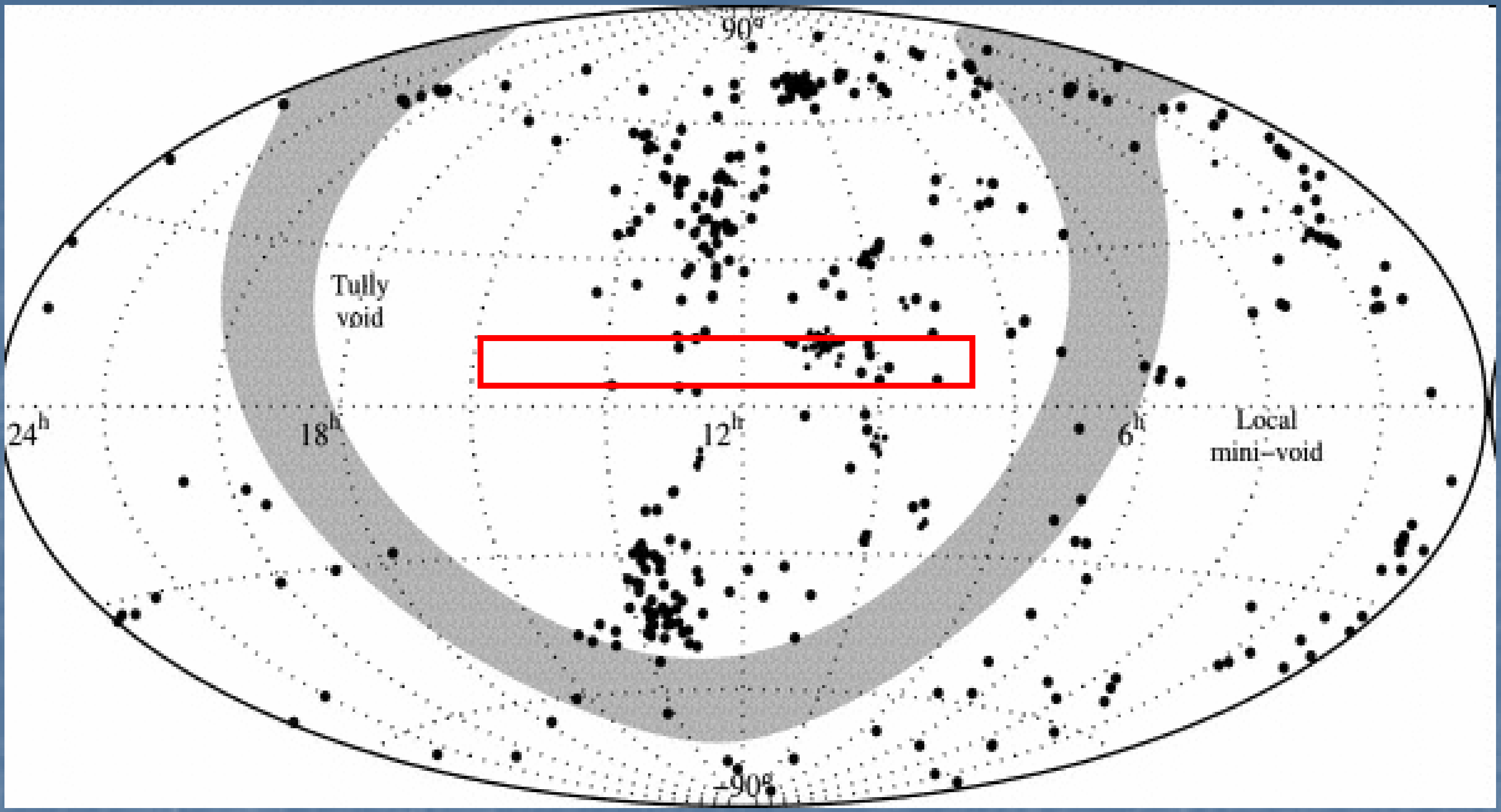
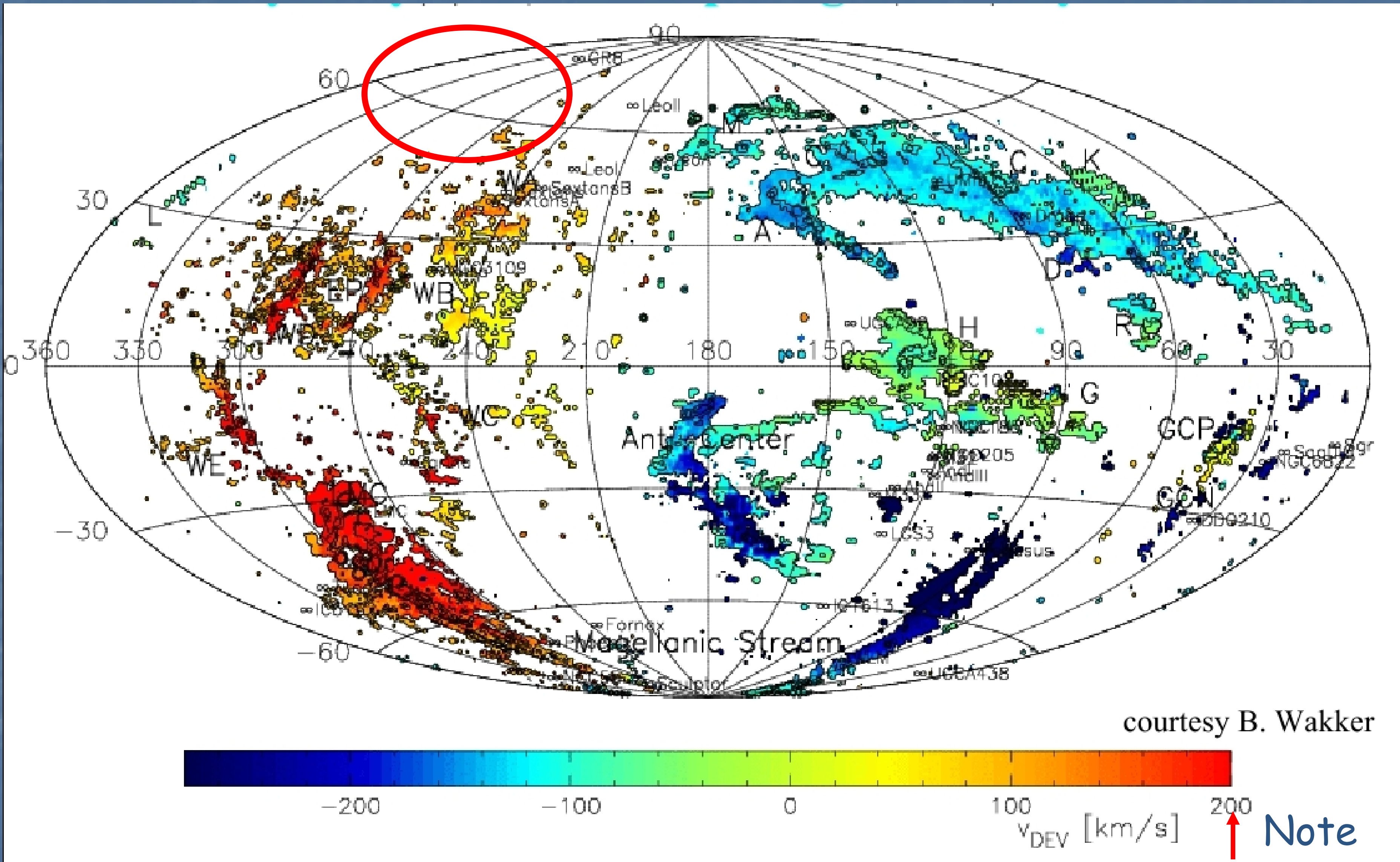
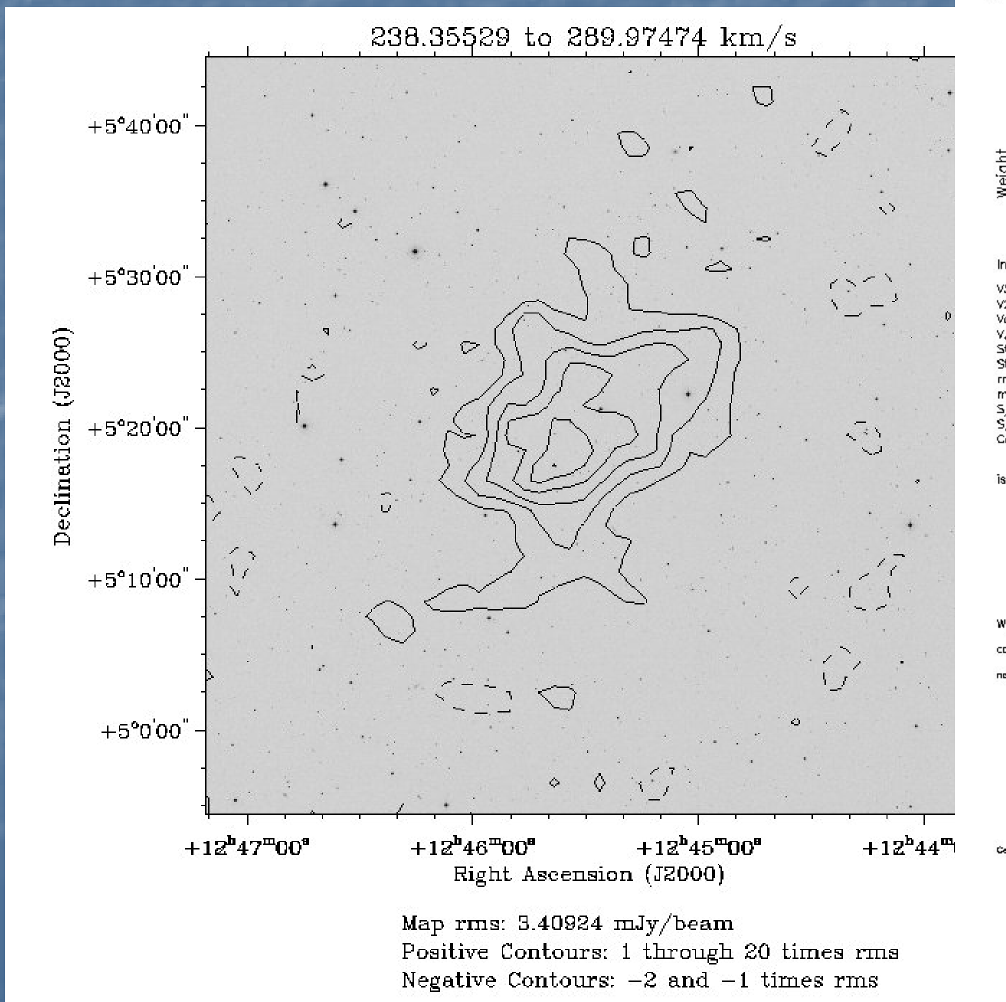
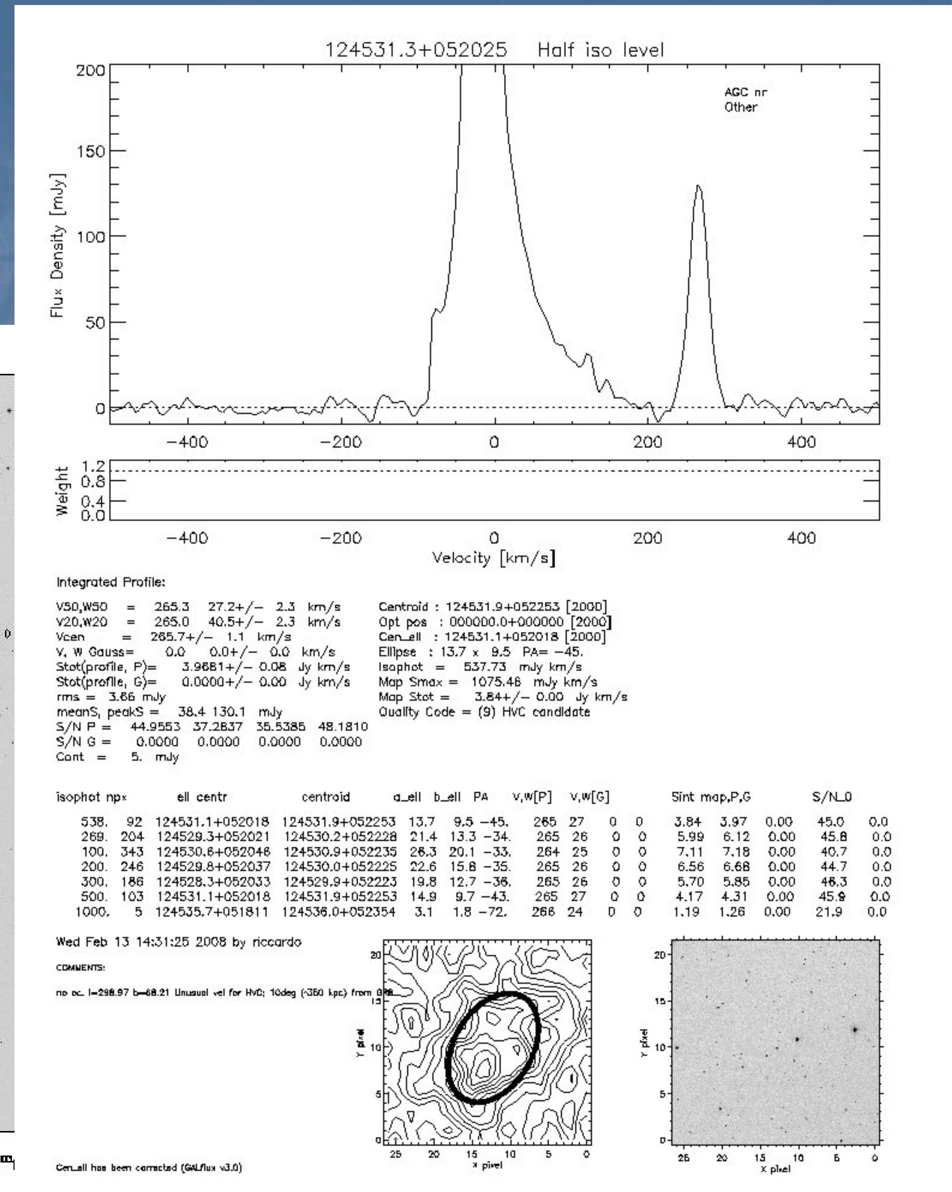


ALFALFA region maps onto Karachentsev et al catalog as shown above in red and onto HVC sky distribution as shown in next image…


90
60
30
0
-30
-60
360
330
300
270
240
210
180
150
90
60
30
L
WA
WB
WC
WE
EP
M
A
C
K
D
R
H
G
GCP
GCN
Anti-Center
Magellanic Stream
LeoII
LeoI
SextansB
SextansA
Fornax
UGCA438
LGS3
courtesy B. Wakker
-200
-100
0
100
200
v_{DEV} [km/s]
Note

22 very compact HVCs are found in the ALFALFA region… they are good baryonic counterparts to minihalo candidates





ALFALFA Minihalo Candidates at d=1 Mpc

•Mean HI Mass	$3x10^5$ solar
•Mean HI Diameter	0.7 kpc
•Mean avged HI column density	$10^{19.1}$ cm^{-2}
•Mean avged HI density	0.006 cm^{-3}
•Mean total mass within R_{HI}	$3x10^7$ solar

Sternberg et al (2002) Minihalo Template @ P=10 cm^{-3} K

•HI Mass	$3x10^5$ solar
•HI Diameter	0.7 kpc
•Peak HI column density	$10^{19.6}$ cm^{-2}
•WIM Mass	$6x10^6$ solar
•Total mass within R_{vir}	$3x10^8$ solar

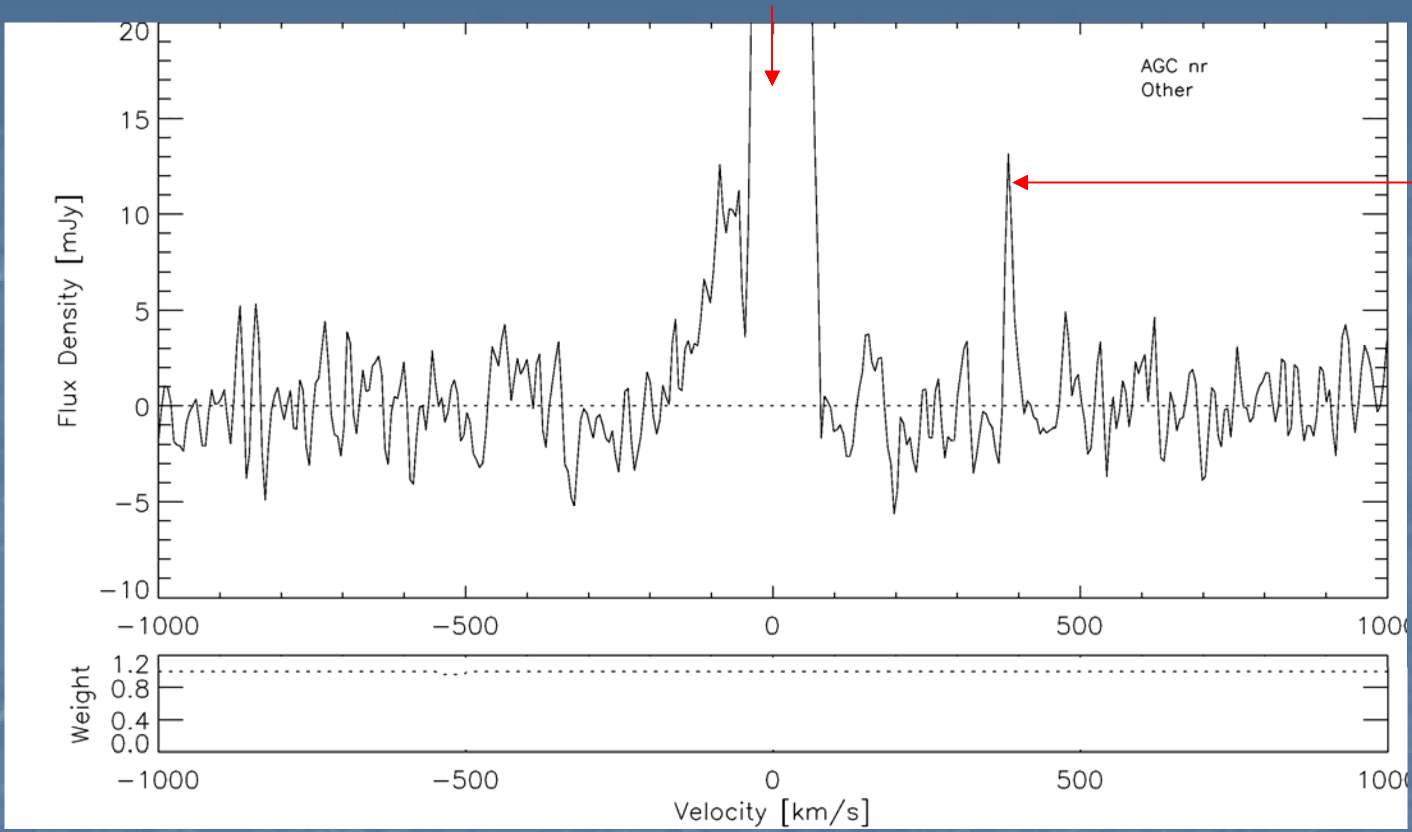
At the distance of nearby groups of galaxies, the ALFALFA minihalo candidates would have been below the sensitivity limit of extant HI surveys.

We have found a subset of the HVC phenomenon that appears to be compatible with the LG minihalo hypothesis.

Other interpretations are possible, we have not proved that the candidates are LG minihalos, but that is a tantalizing possibility.

However….

MW (local) emission



HI feature with no optical counterpart

$$V_{helio} = 386 km/s$$

$$W_{50} = 10 km/s$$

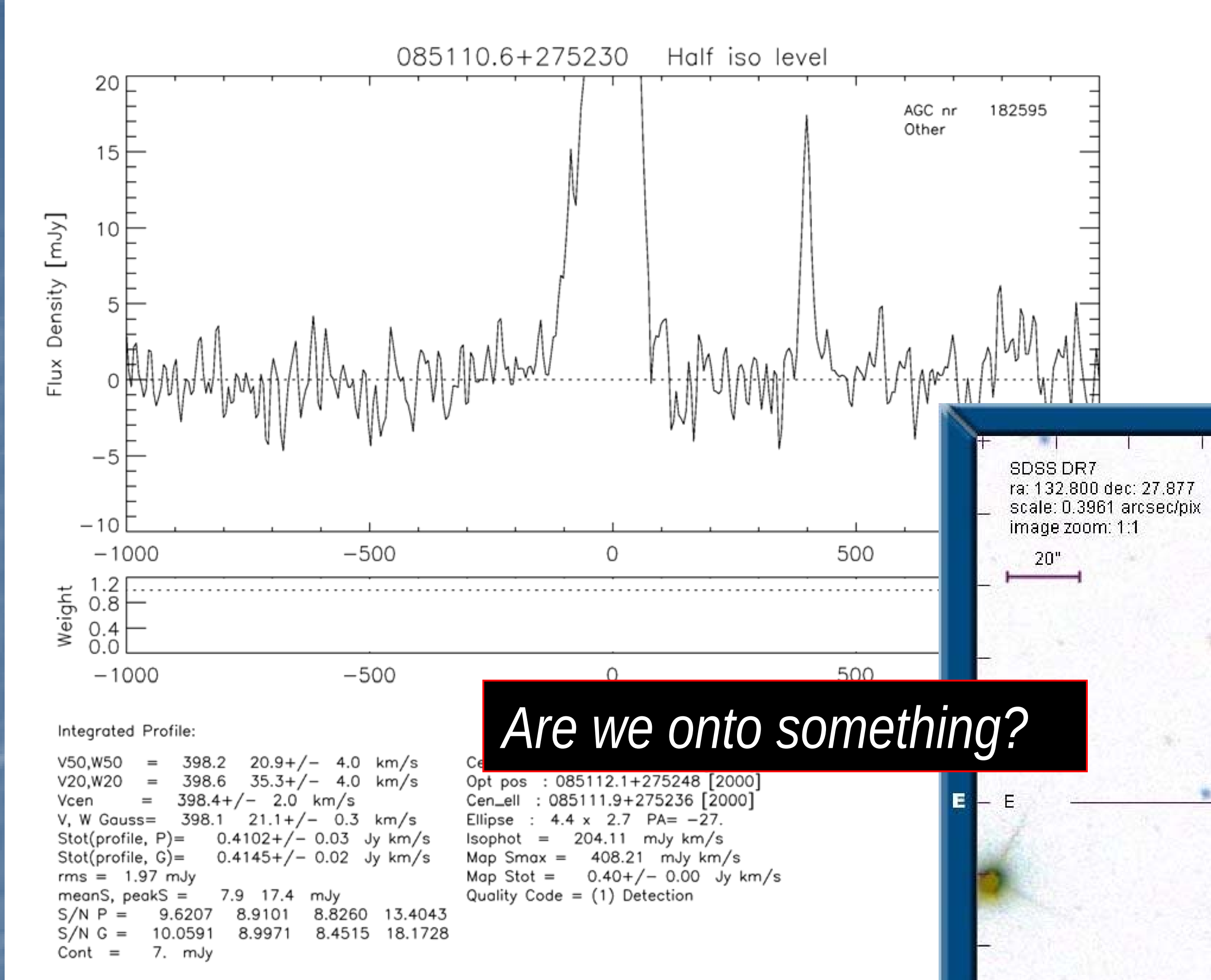
$$M_{HI} = 4.7 \times 10^4 D^2 M_{sun}$$

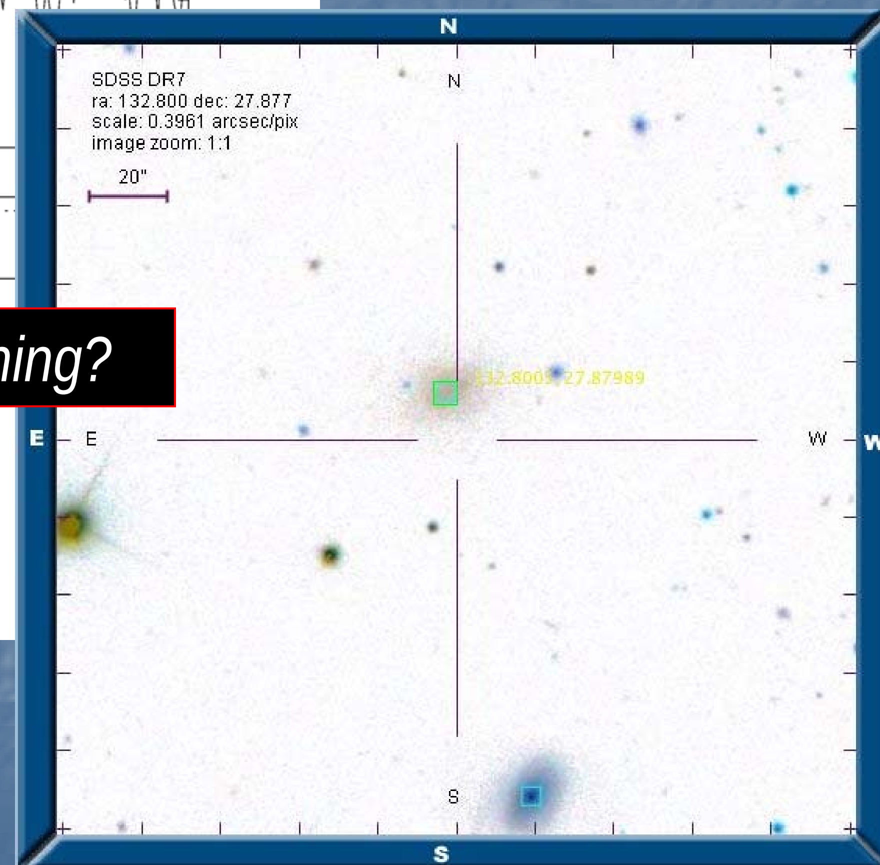
V_LG~300

What is this:?

- A very anomalous HVC?
- RFI?
- Extragalactic??

Half a Degree away we find…..





Are we onto something?

Half degree away from cloud, another HI source is found with similar vel; this one however has optical counterpart with matcing optical redshift…