HI in the Local Group: what analogous groups tell us

D.J. Pisano

(NRC Associate, Naval Research Lab)

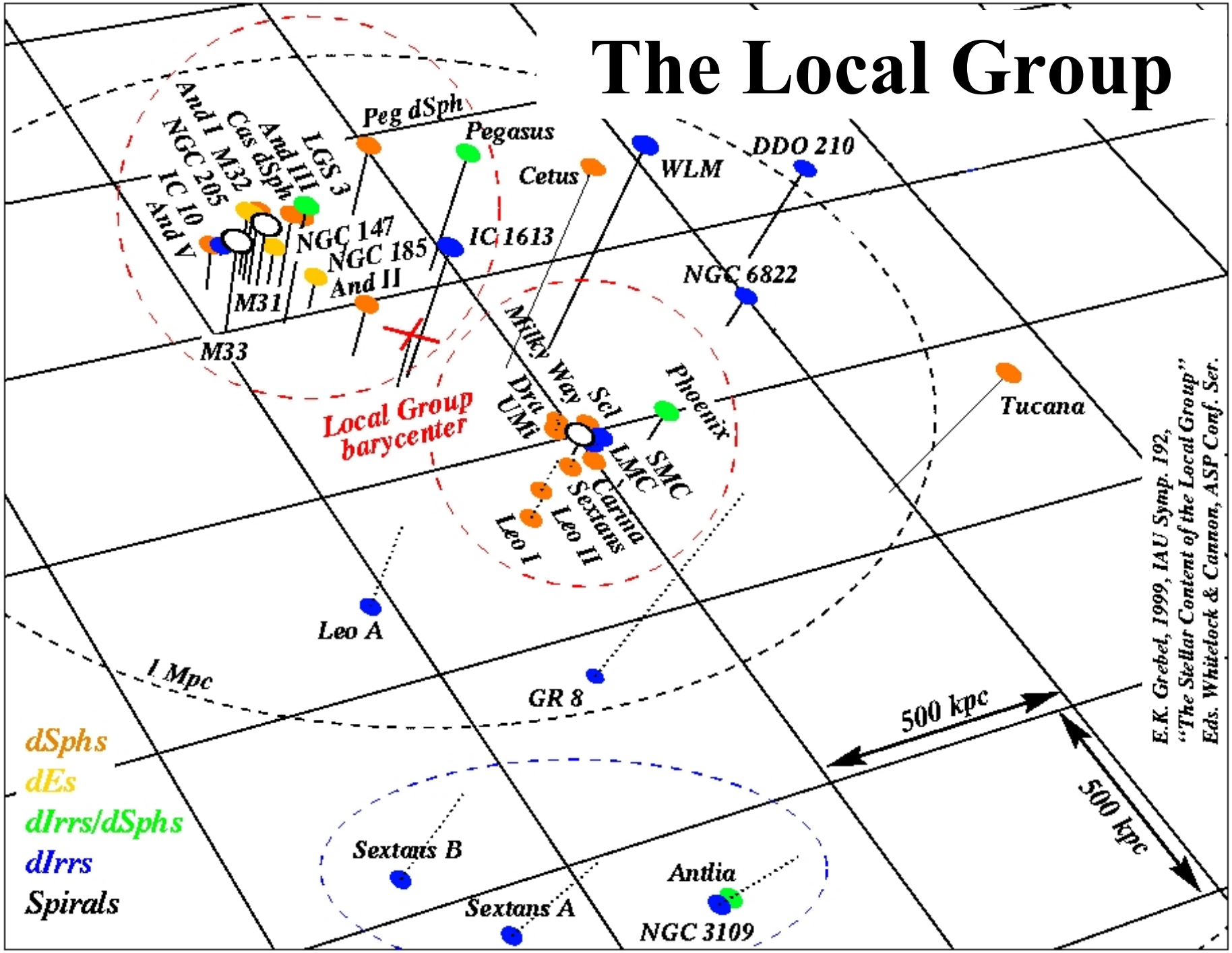
David Barnes (Melbourne), Brad Gibson (Swinburne), Lister Staveley-Smith (ATNF), Ken Freeman (RSAA), Virginia Kilborn (Swinburne)

Questions to be addressed:

Are the HI clouds (i.e. the High Velocity Clouds) seen around the Milky Way and within the Local Group associated with galaxy formation?

Are there too few dIrr's in the Local Group?

What do these data say about models of galaxy formation and the evolution of galaxies in different environments?


The Local Group
Peg dSph
Pegasus
Cetus
WLM
DDO 210
And I
M32
Cas dSph
And III
LGS 3
NGC 205
IC 10
And V
NGC 147
NGC 185
And II
IC 1613
M31
M33
NGC 6822
Milky Way
Local Group barycenter
Dra
UMi
Scl
Phoenix
Tucana
LMC
SMC
Carina
Sextans
Leo II
Leo I
Leo A
1 Mpc
GR 8
500 kpc
500 kpc
dSphs
dEs
dIrrs/dSphs
dIrrs
Spirals
Sextans B
Antlia
Sextans A
NGC 3109
E.K. Grebel, 1999, IAU Symp. 192,
"The Stellar Content of the Local Group"
Eds. Whitelock & Cannon, ASP Conf. Ser.

Observational Motivation:
Milky Way High Velocity Clouds (HVCs)

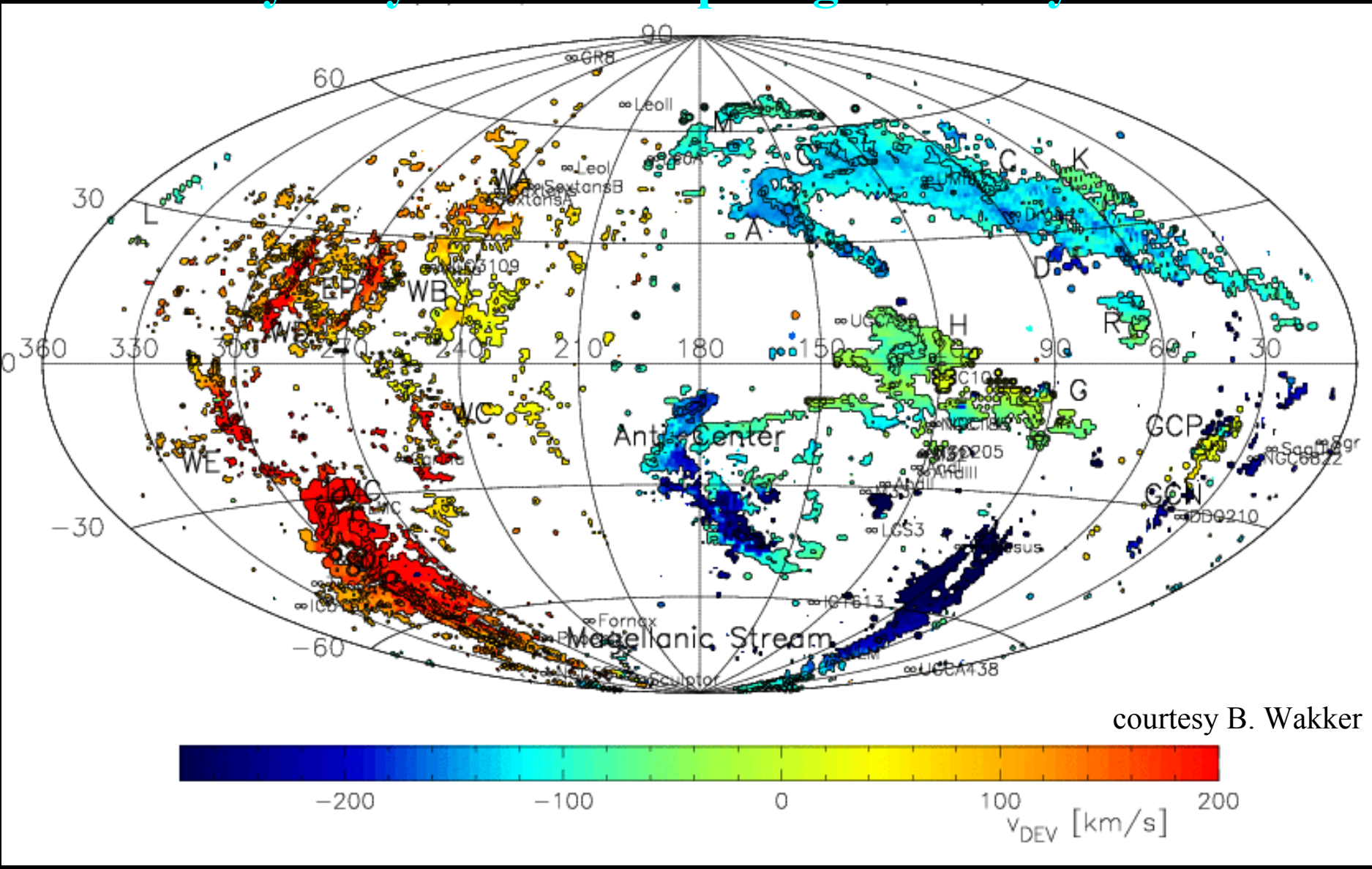
HVCs are HI clouds, first discovered in 1963, moving at velocities inconsistent with Galactic Rotation.

HVCs lack stars

HVCs have *mostly* unknown distances

HVCs probably have a variety of origins

Milky Way/Local Group High Velocity Clouds



Local Group HVCs

Blitz et al. (1999) suggested that most HVCs were associated with low-mass dark matter halos and have D ~ 1 Mpc and $M_{HI} \sim 10^7\ M_\odot$.

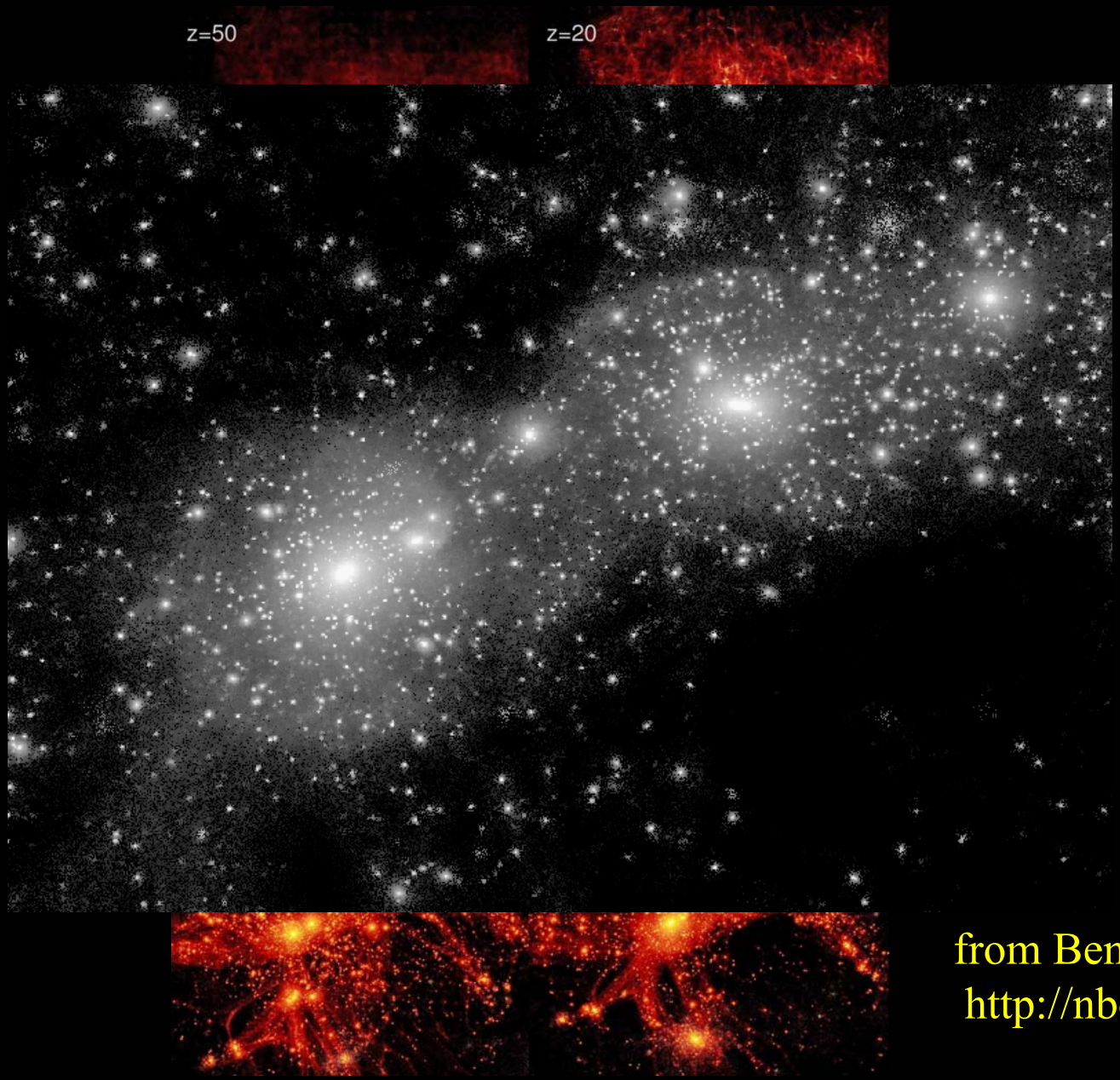
Braun & Burton (1999) suggested that just the compact HVCs had these properties.

de Heij et al. (2002) proposed the CHVCs are concentrated around the Milky Way and M31 with a Gaussian distance distribution with D ~ 150 - 200 kpc and $M_{HI} \leq 10^7\ M_\odot$.

All of these models associate HVCs with galaxy formation.

They all associate HVCs with dark matter halos.

The Formation of the Local Group



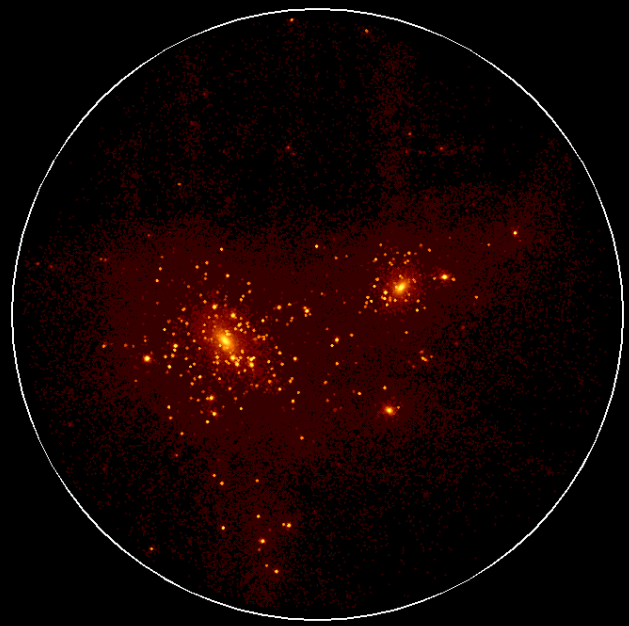
from Ben Moore
http://nbody.net

"Missing Satellite" Problem

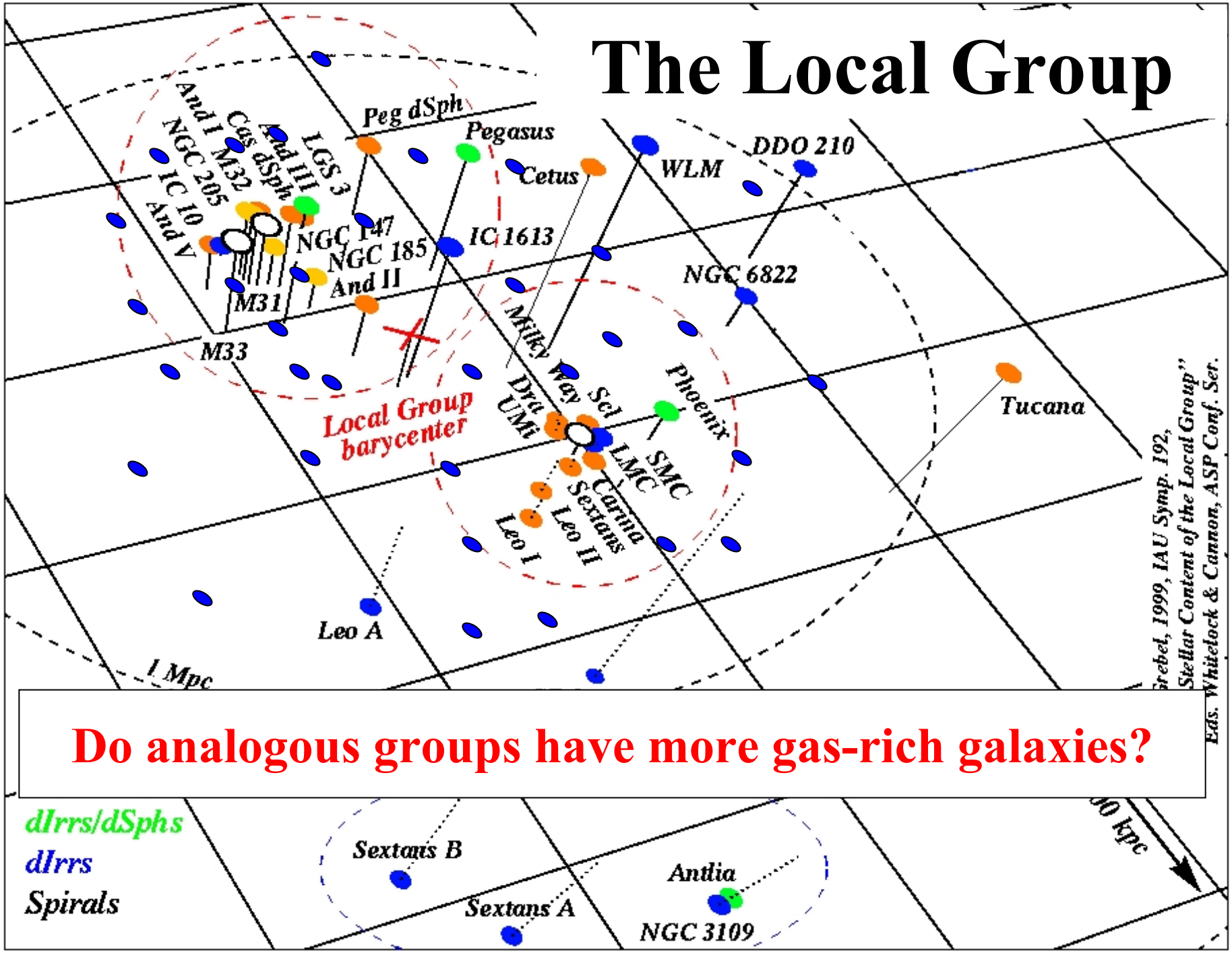
Cold Dark Matter models of galaxy formation predict ~ 300 dark matter halos in the Local Group, most with velocity widths less than 20 km/s, but only ~ 20 satellites known. (~ 270 CHVCs)

Is the Local Group typical?

Could the remaining DM halos be associated with HVCs or are they devoid of baryons?



from Klypin et al. (1999)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Sextans
Leo II
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1 Mpc
Do analogous groups have more gas-rich galaxies?
dIrrs/dSphs
dIrrs
Spirals
Sextans B
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Grebel, 1999, IAU Symp. 192,
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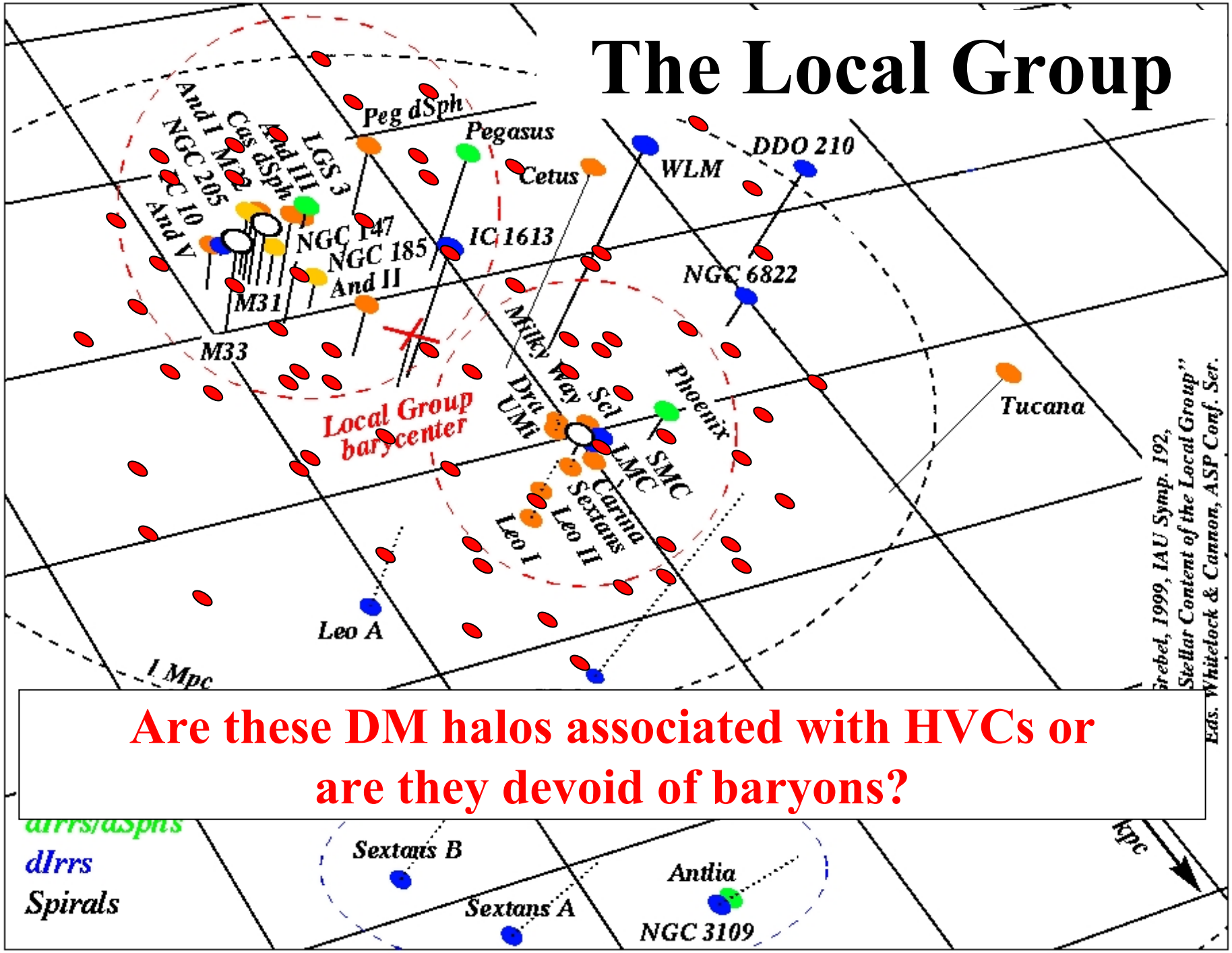
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Are these DM halos associated with HVCs or are they devoid of baryons?
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NGC 3109
kpc
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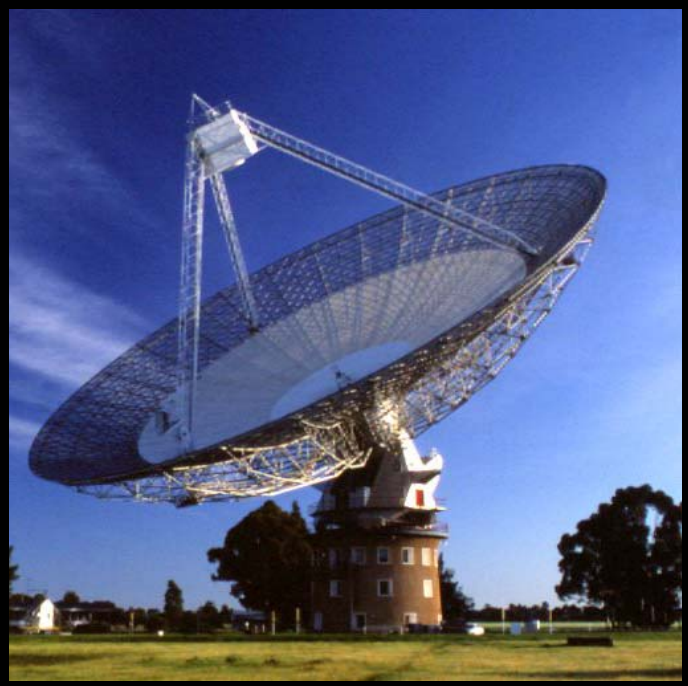
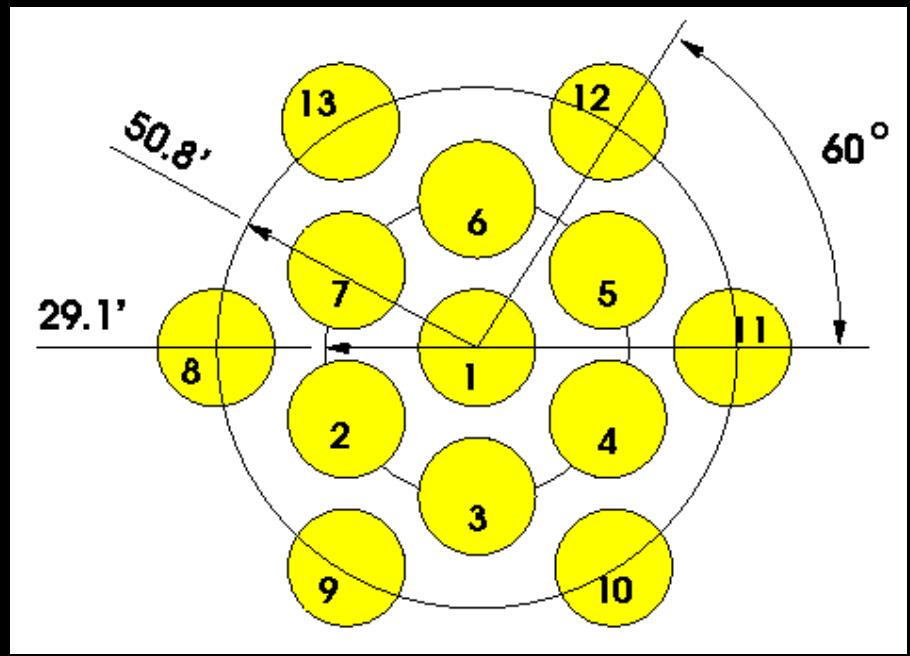
Our Group Survey

If HVCs are associated with galaxy formation in the Local Group, perhaps we should search in analogous groups.

We observed the entire area of 6 spiral-rich, loose groups with the Parkes Multibeam and ATCA.





Group Properties

Groups observed: LGG 93, 106, 180, 293, 478, HIPASS Group 3

Composition: All spiral + irregular galaxies No X-ray emission.

Group distances: 10.6 - 13.4 Mpc

Number of galaxies in optically defined group: 3 - 9

Group velocity dispersions: ~ 30 - 300 km/s

Average diameter of groups: ~ 1.6 Mpc

Average galaxy-galaxy separation: ~ 550 kpc

Group dynamical masses: log M ~ 11.7 - 13.6 $M_{\odot}$

Parkes Multibeam Observations

Groups observed: LGG 93, 106, 180, 293, 478, HIPASS Group 3

Area observed: ~ 1-2 Mpc^2 ≈ 25 - 35 sq. deg.

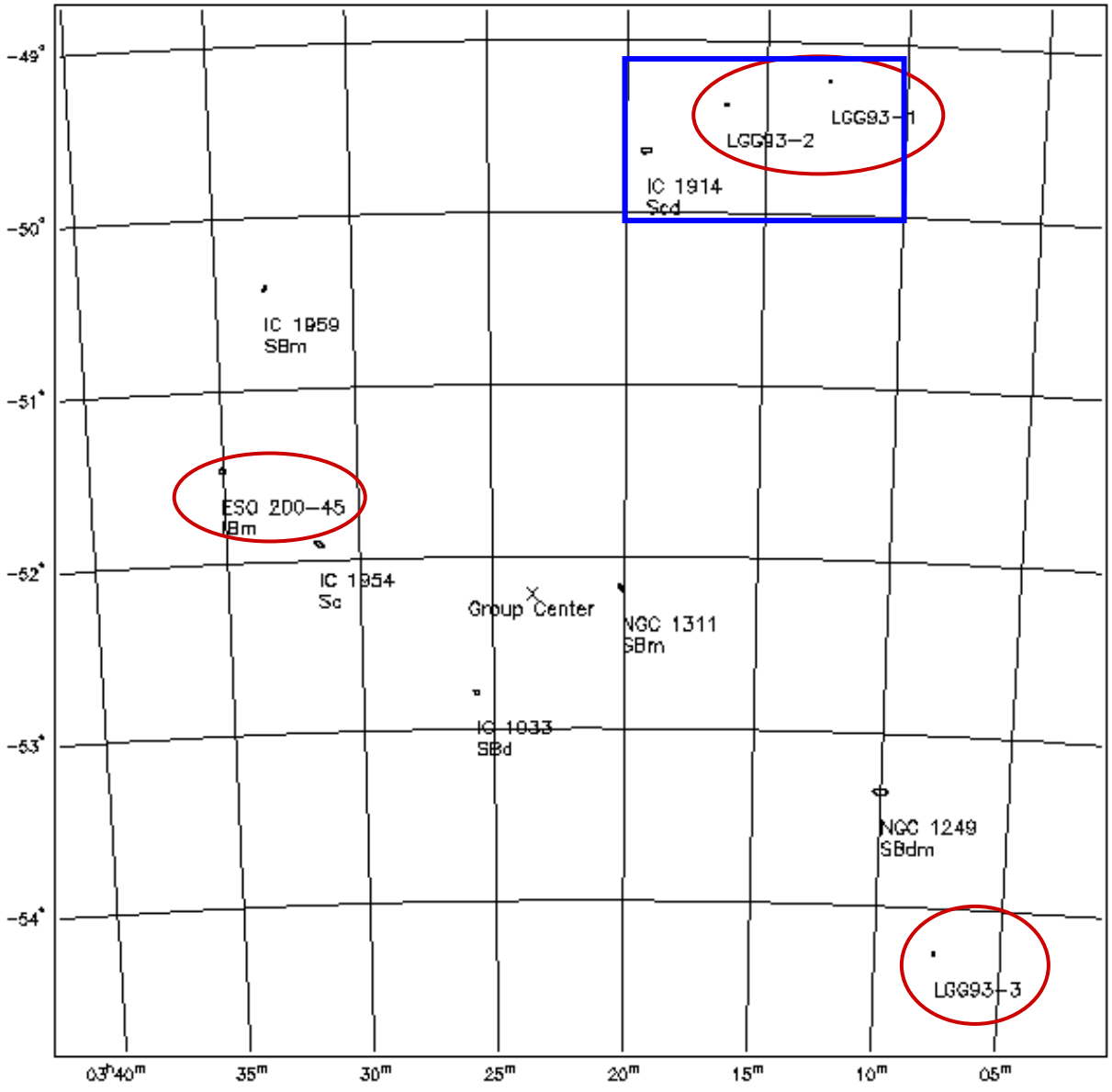
Velocity Resolution: 1.65 or 3.3 km/s

Velocity Coverage: 1700 - 3400 km/s

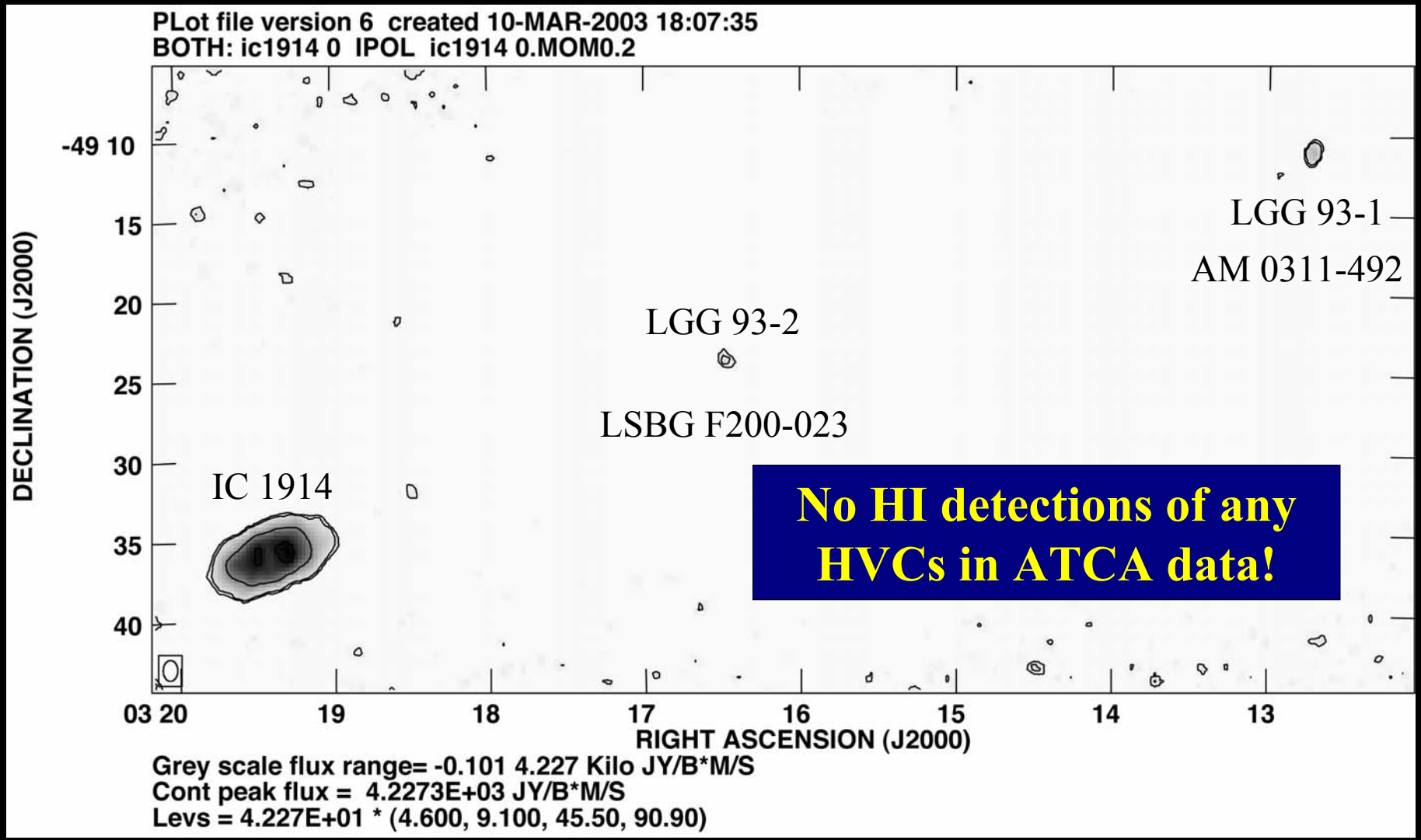
Spatial Resolution: 14′ ~ 50 kpc

Mass sensitivity (1σ ΔM_{HI} over 3.3 km/s): $5 - 8 \times 10^5 M_\odot$

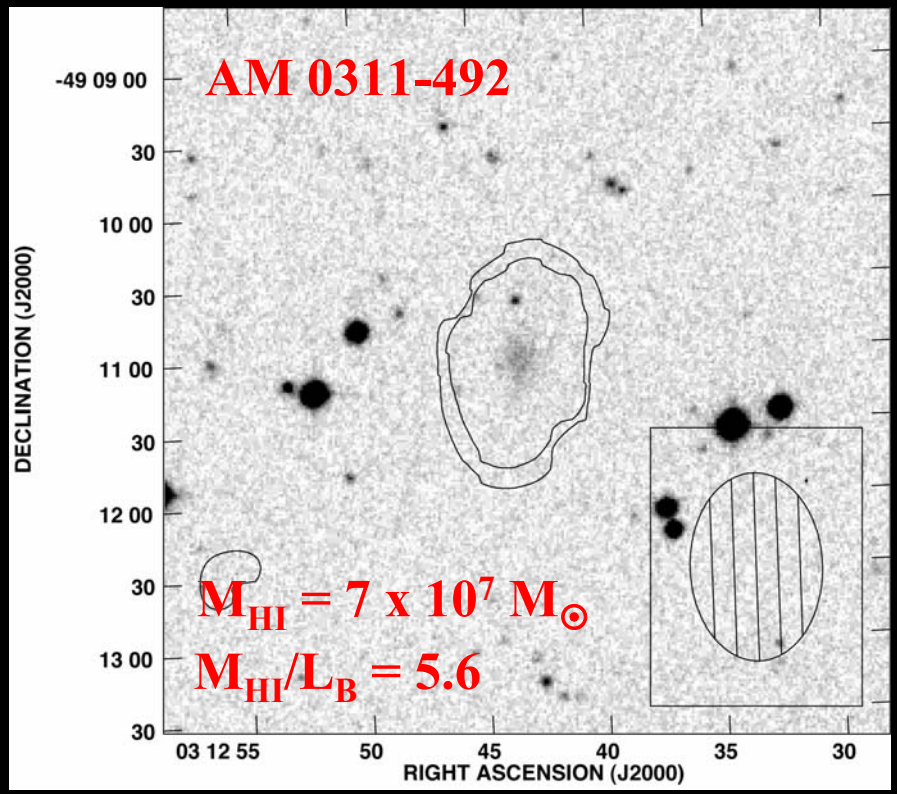
New Detections in LGG 93

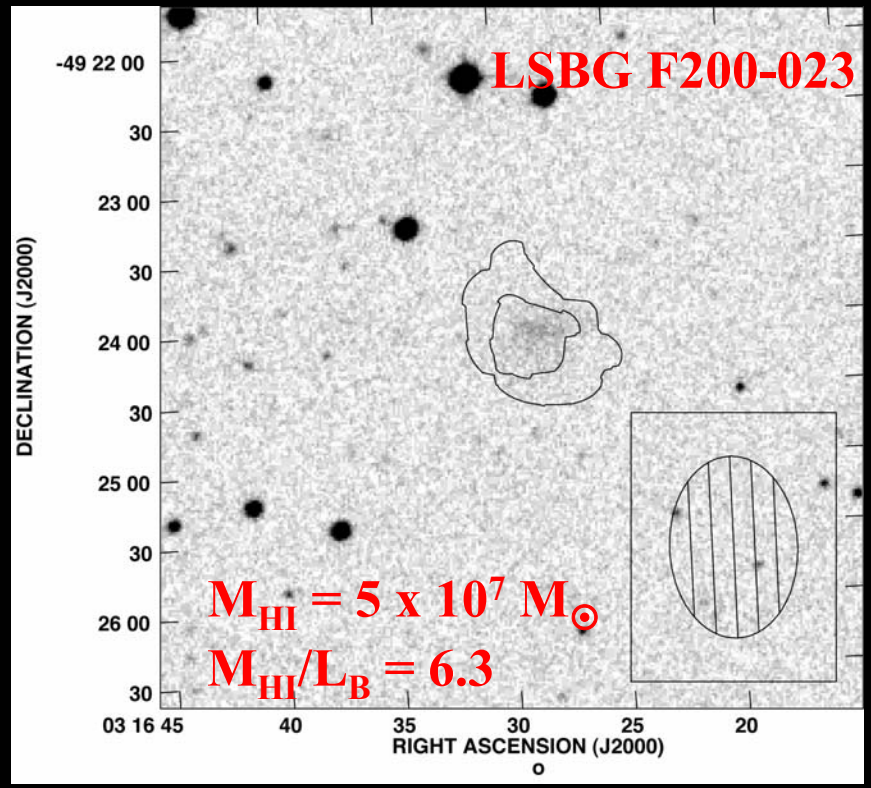


ATCA Follow-Up



Optical Counterparts

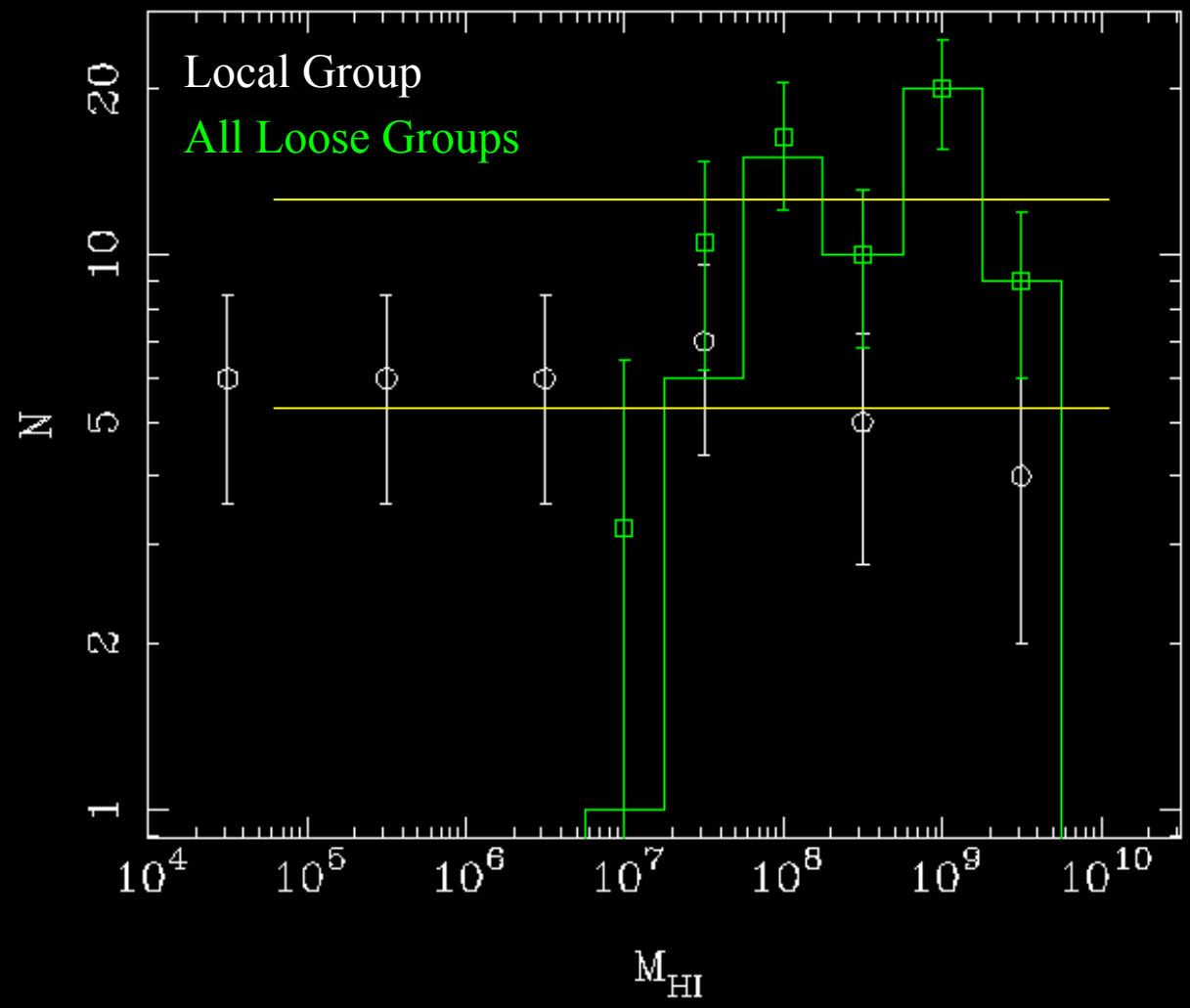




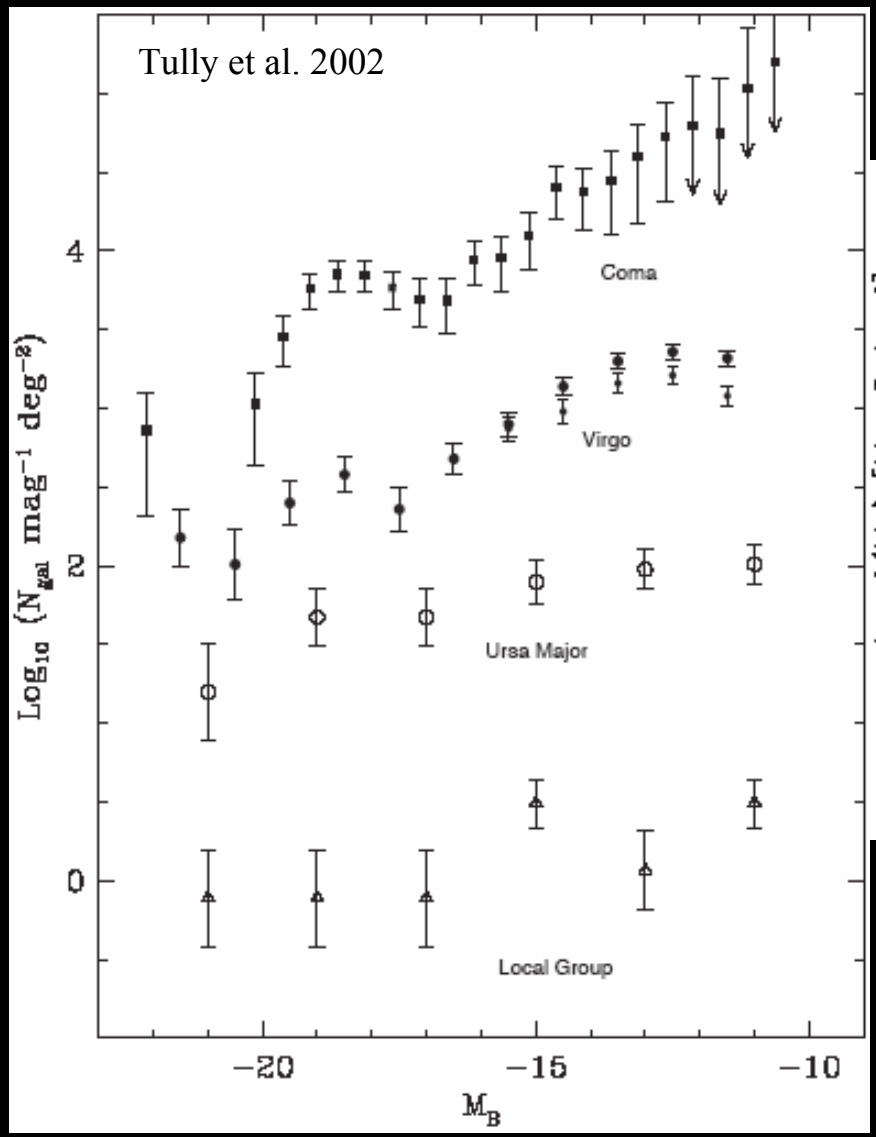
All 64 detections have optical counterparts.

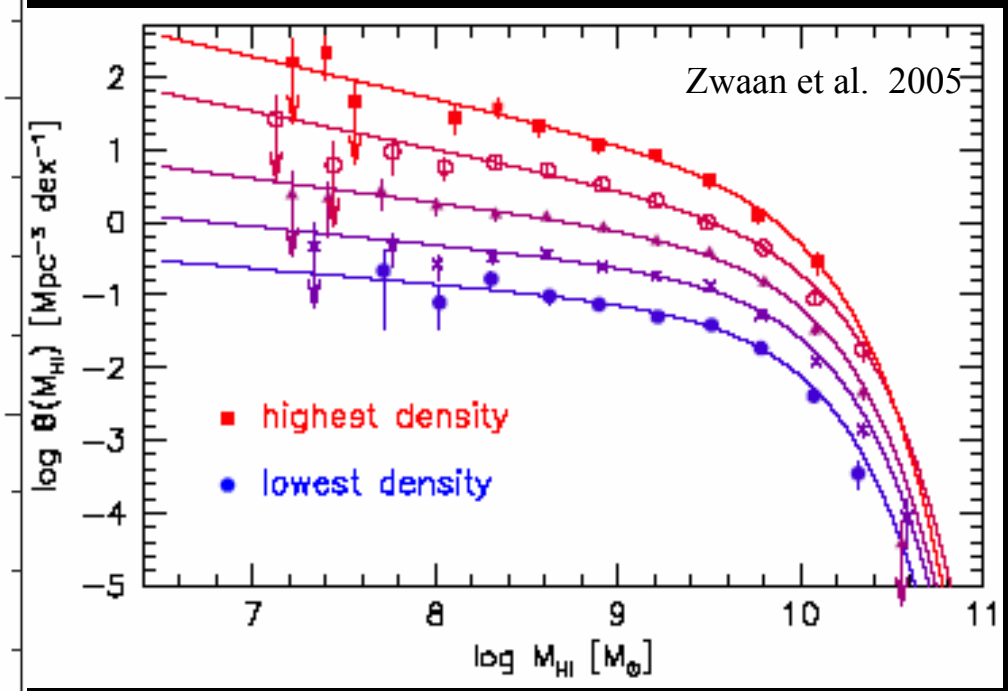
No HI clouds without stars found yet!

HI Mass "Function"

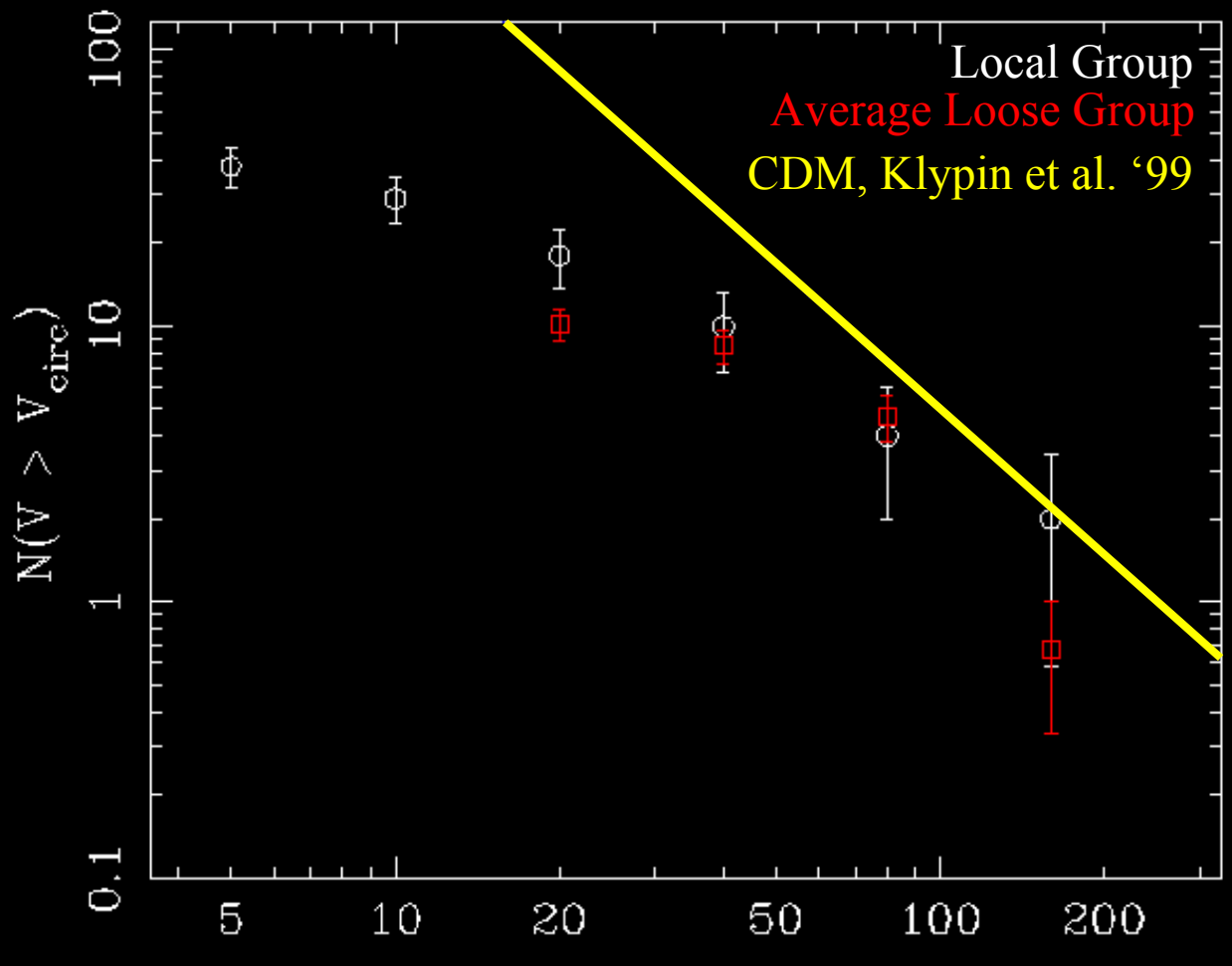


HIMF in various environments





Halo Mass Distribution

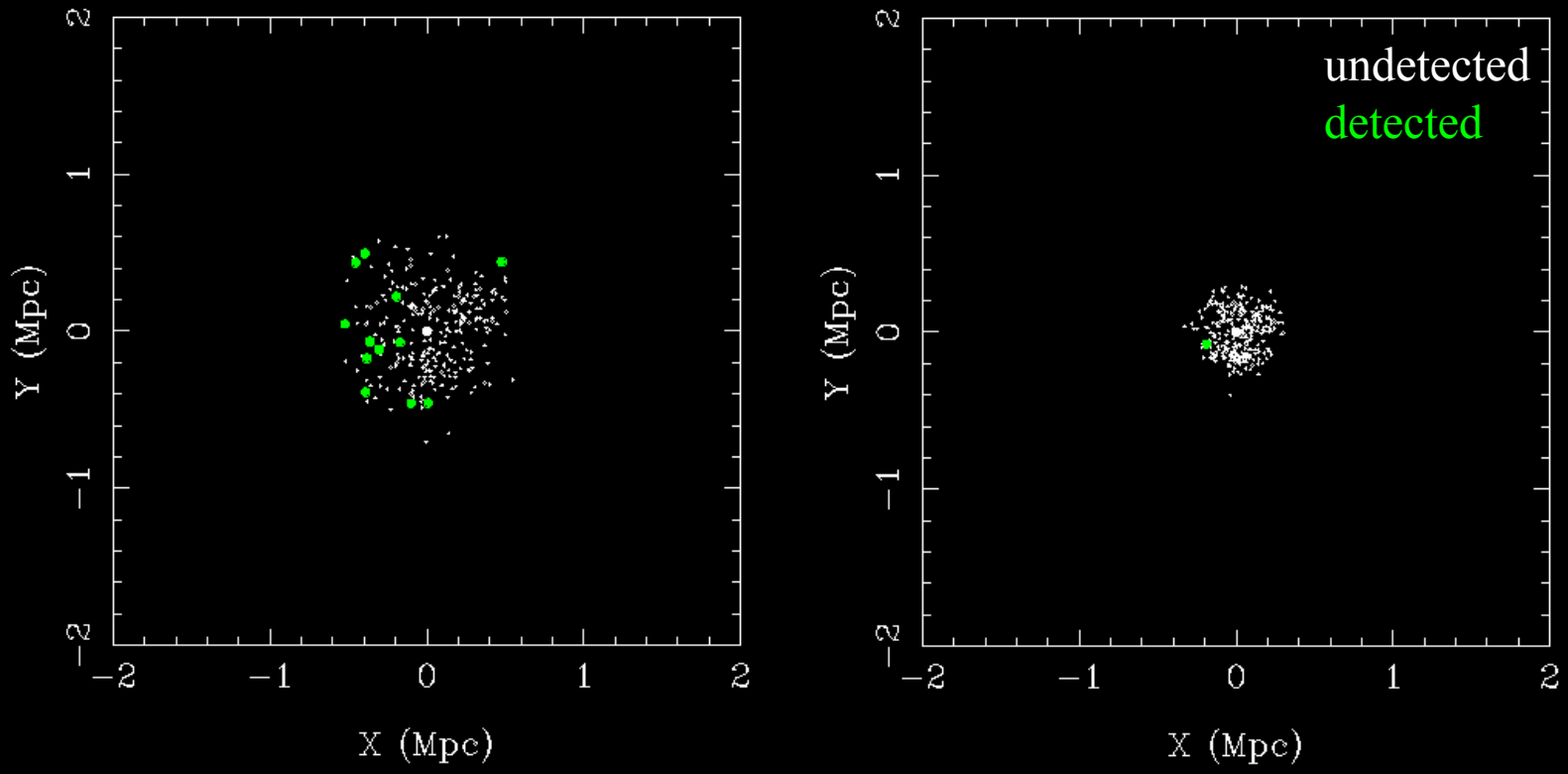


$V_{circ} \approx W_{20}/2 \sin i$

A simple CHVC model

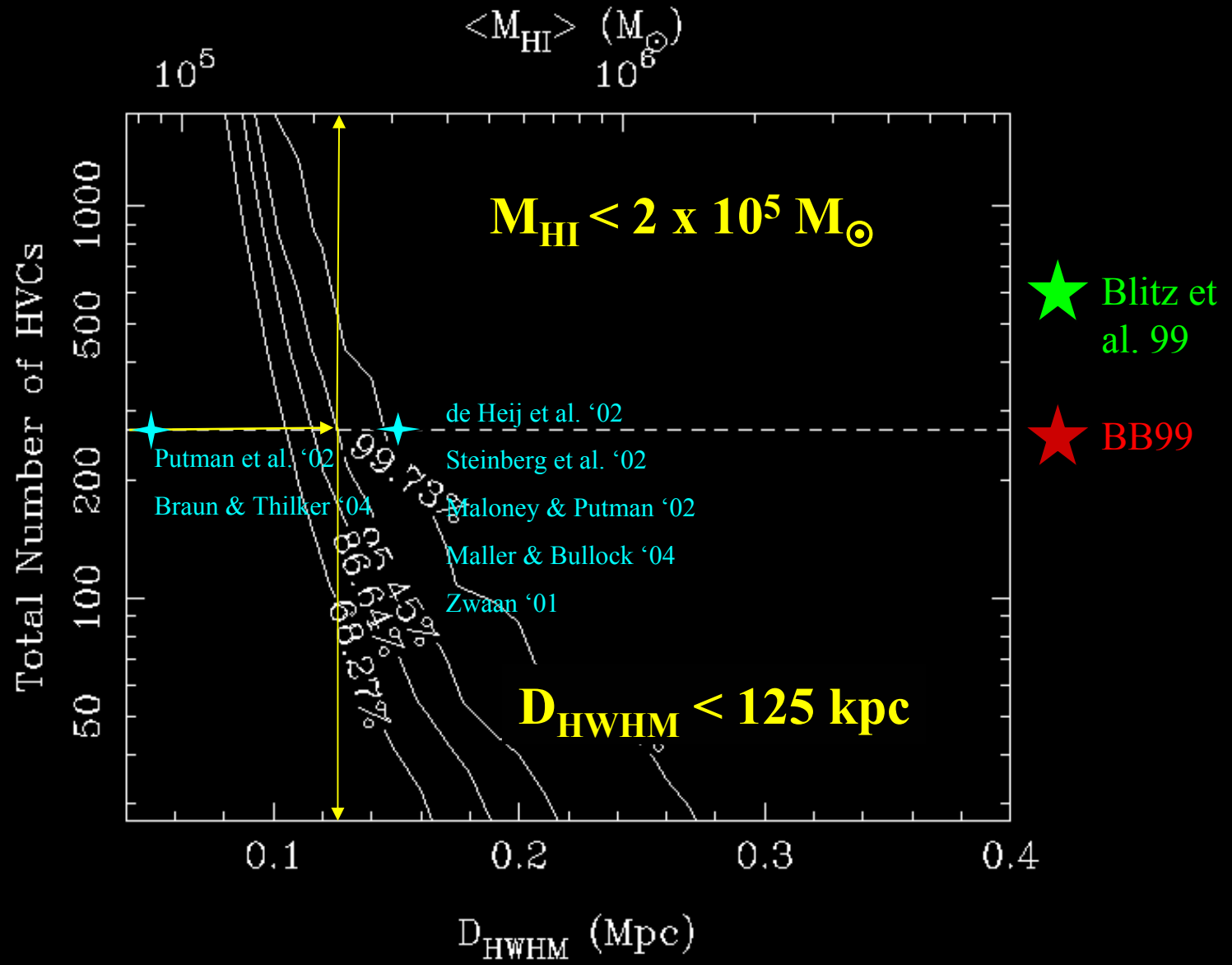
If CHVCs are associated with the formation of the Local Group or the galaxies therein, then they should be in other groups.

(Pisano et al. 2004, ApJ, 610, L17; Pisano et al. ,2006, in preparation)



As D_{HWHM} decreases, we expect fewer detections.
As the population decreases, we expect fewer detections.

Combined Constraints for 6 groups



Implications for HVCs

Non-detections imply CHVCs must be within $D_{HWHM} < 125$ kpc at 95.45%confidence level.

$\Rightarrow$ Average CHVC $M_{HI} < 2 \times 10^5 M_\odot$

$\Rightarrow$ Total HI Mass in CHVCs ~ $5 \times 10^7 M_\odot$

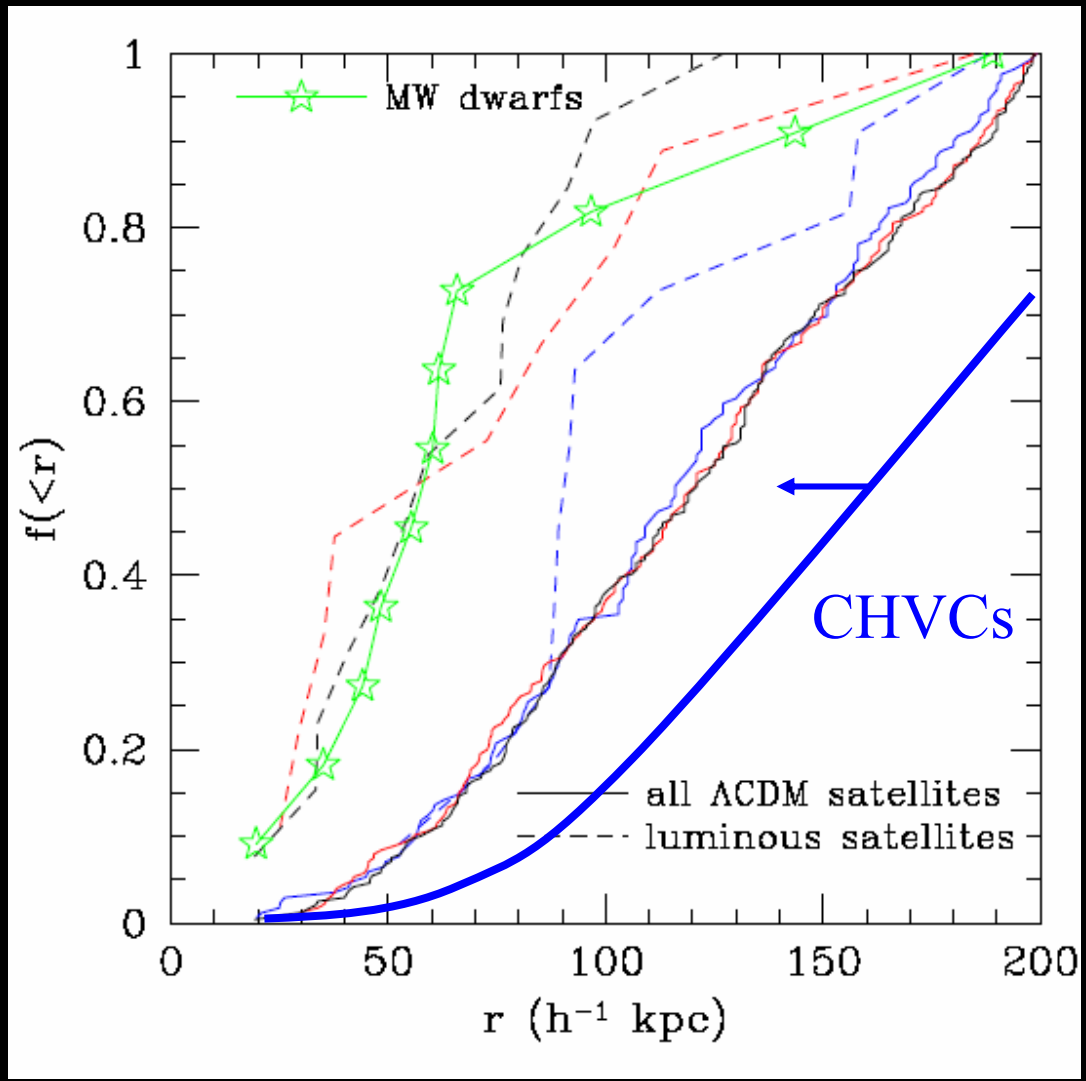
Therefore,

There is very little *NEUTRAL* gas around the Milky Way to participate in galaxy formation. Yet, it can still provide fuel for star formation. May be plenty of *ionized* gas!

Furthermore,

The total mass in CHVCs is much less than the total mass in the Milky Way or M31, and they are dynamically unimportant.

Spatial Distribution of HVCs



CDM Halos

$D_{HWHM} \sim 100$ kpc

MW dwarfs

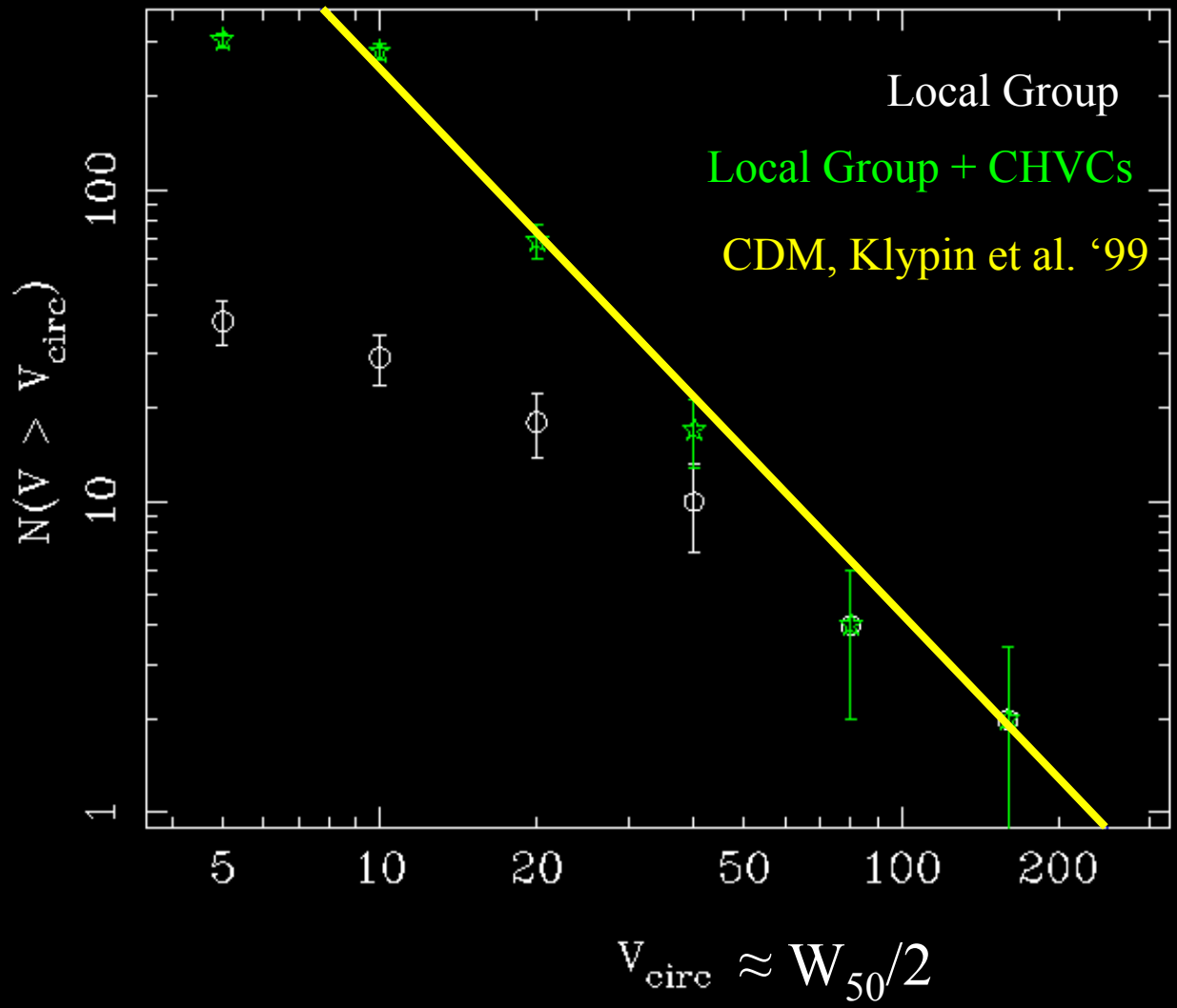
$D_{HWHM} \sim 50$ kpc

CHVC limit

$D_{HWHM} < 125$ kpc

CDM Simulation (Kravtsov et al. 2004)

Halo Mass Distribution of HVCs



Conclusions

- Of our ~ 64 Parkes + ATCA HI detections, no HI clouds without stars were were found with $M_{HI} \leq 10^7 M_\odot$!

- Non-detections imply HVCs must be within $D_{HWHM} < 125$ kpc at 95%confidence level. Very little neutral gas remaining for galaxy assembly. ($\leq 5 \times 10^7 M_\odot$) There may be plenty of ionized gas, however.

$\Rightarrow$ There is a consensus between the current models & observations as to the distance and masses of HVCs.

- HI mass function and Halo mass function are similar for our groups and Local Group. The Local Group is not atypical as regards the number of dIrr's.

$\Rightarrow$ Neither are consistent with simple CDM predictions.

- Local Group + CHVC mass function is consistent w/ CDM. Distance limits are also consistent w/ models and Milky Way satellites.

$\Rightarrow$ "Missing Satellites" found???