Gaseous Galaxy Halos

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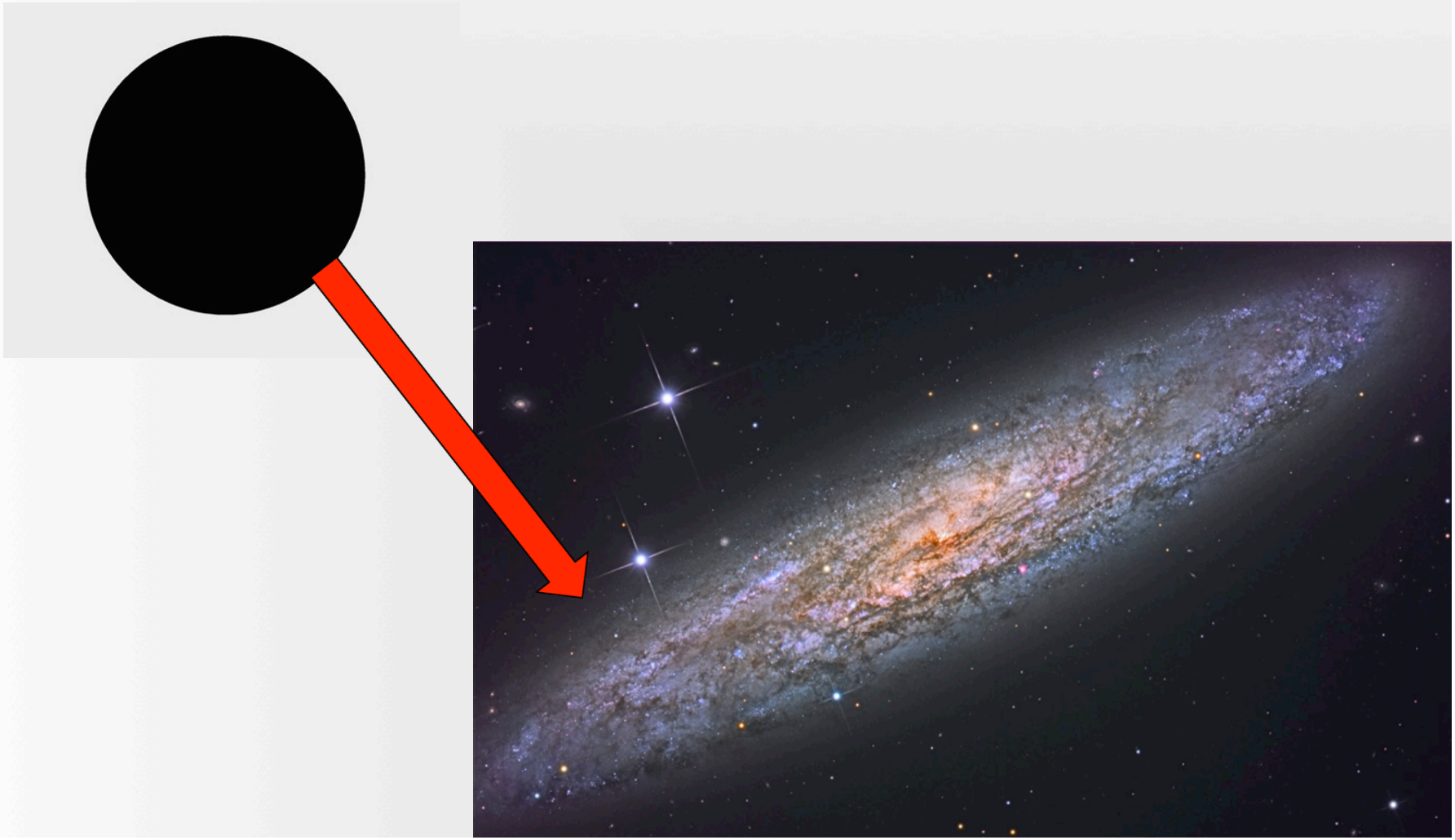
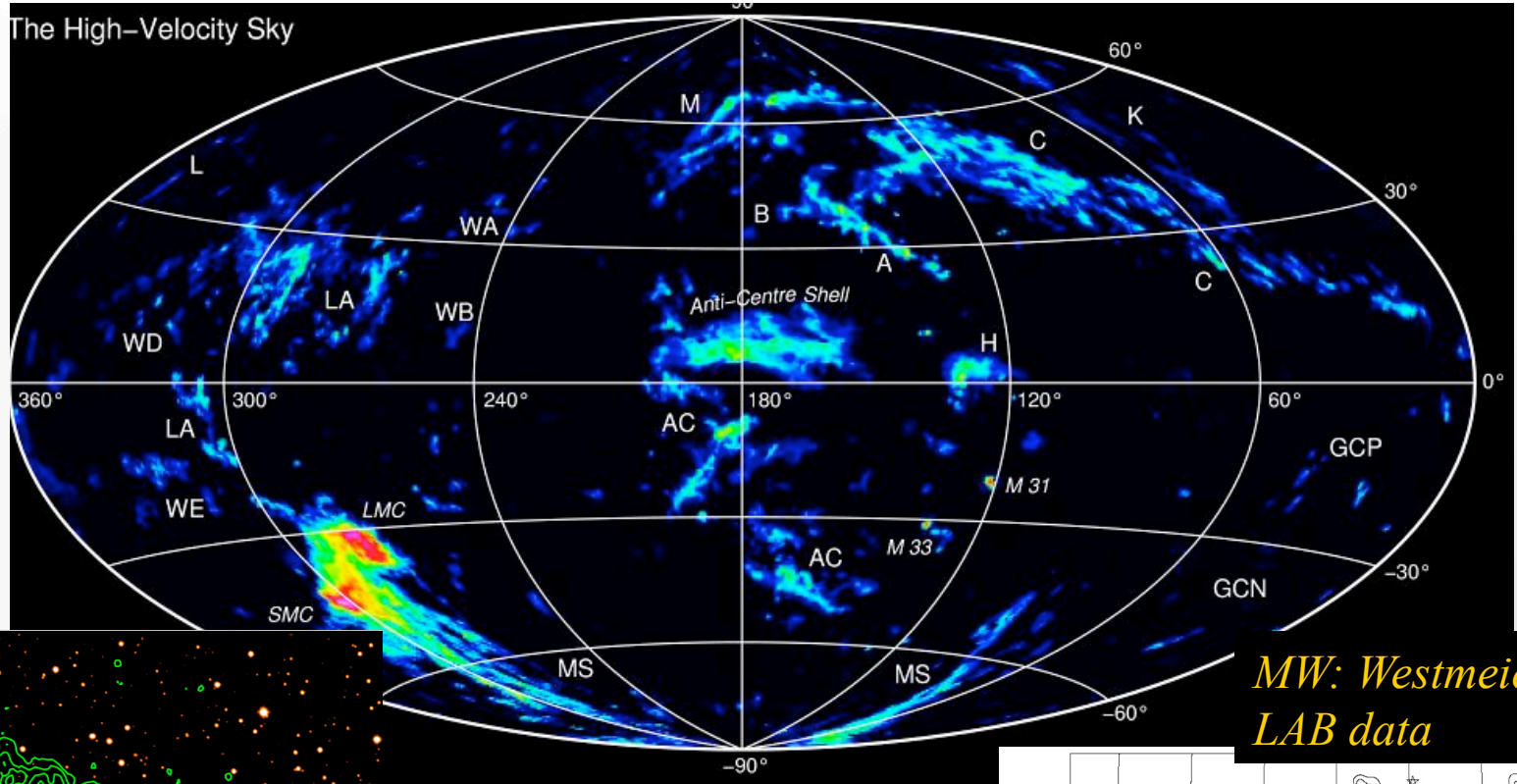


What is the source of gas?

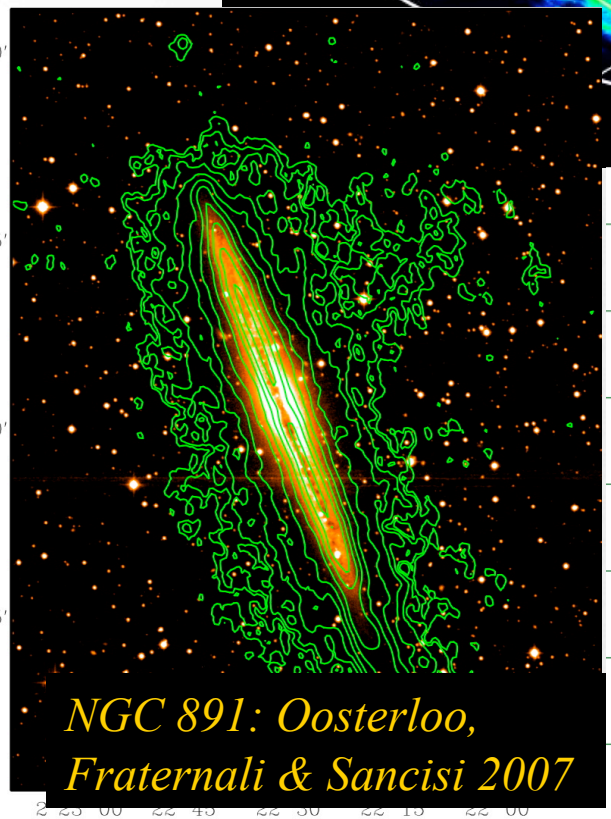
- Cold gas flowing along cosmic filaments
- Gas from hot halo cooling
- ✔ Mergers/satellite accretion (original inflow from above)

Galaxy Gas Flows (observations)

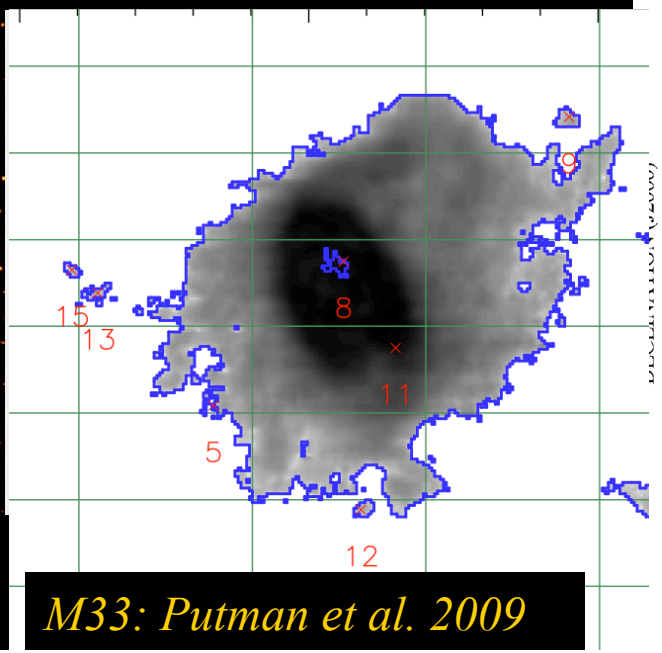
- Is there cool gas beyond galaxies that will become star formation fuel?
- Is their a hot gaseous medium surrounding galaxies?



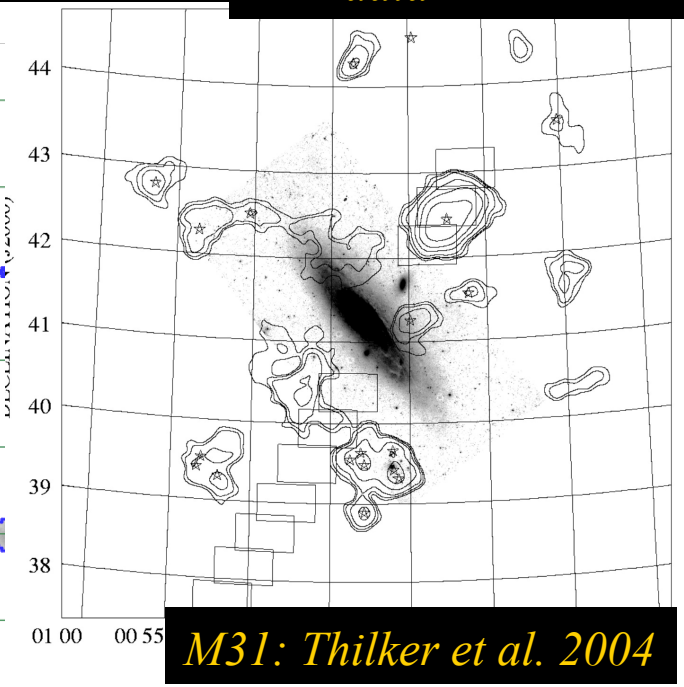
MW: Westmeier et al.; LAB data



NGC 891: Oosterloo, Fraternali & Sancisi 2007

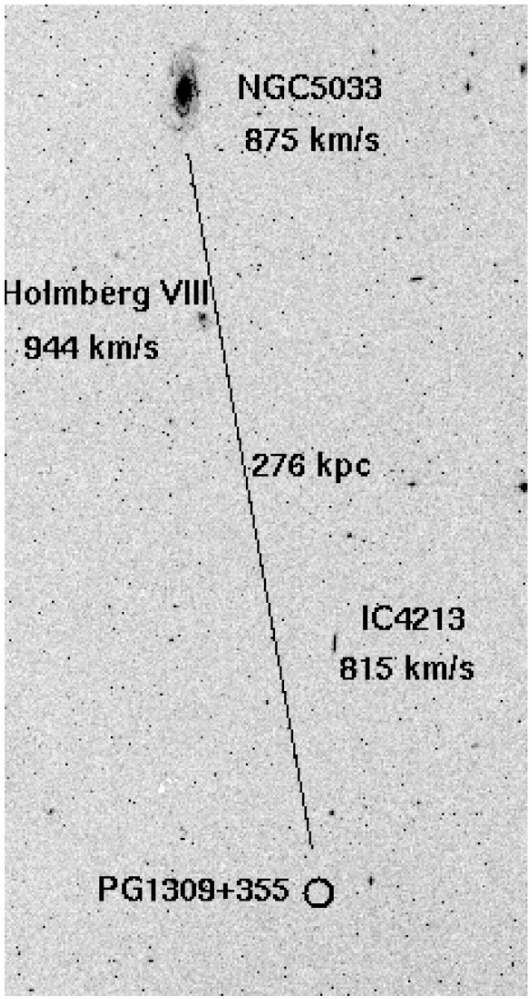


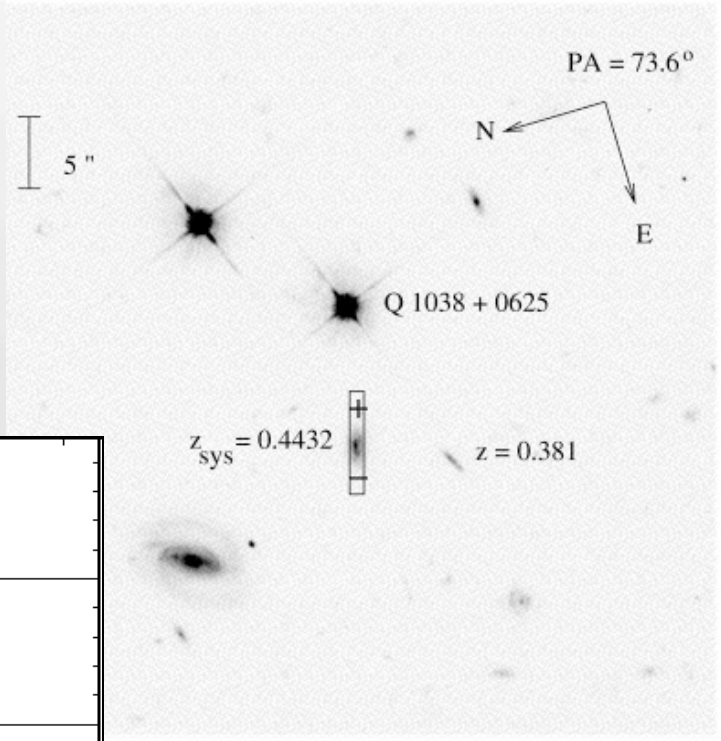
M33: Putman et al. 2009

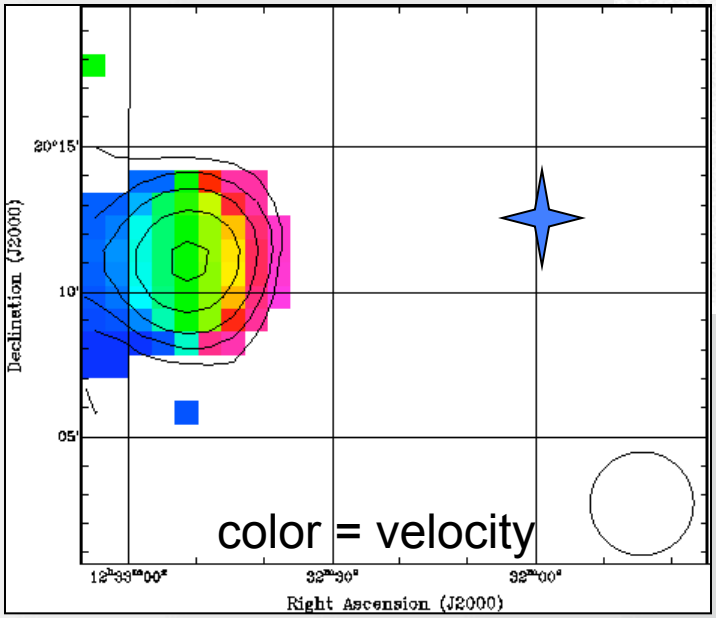


M31: Thilker et al. 2004

Low column density gas in cosmic filaments







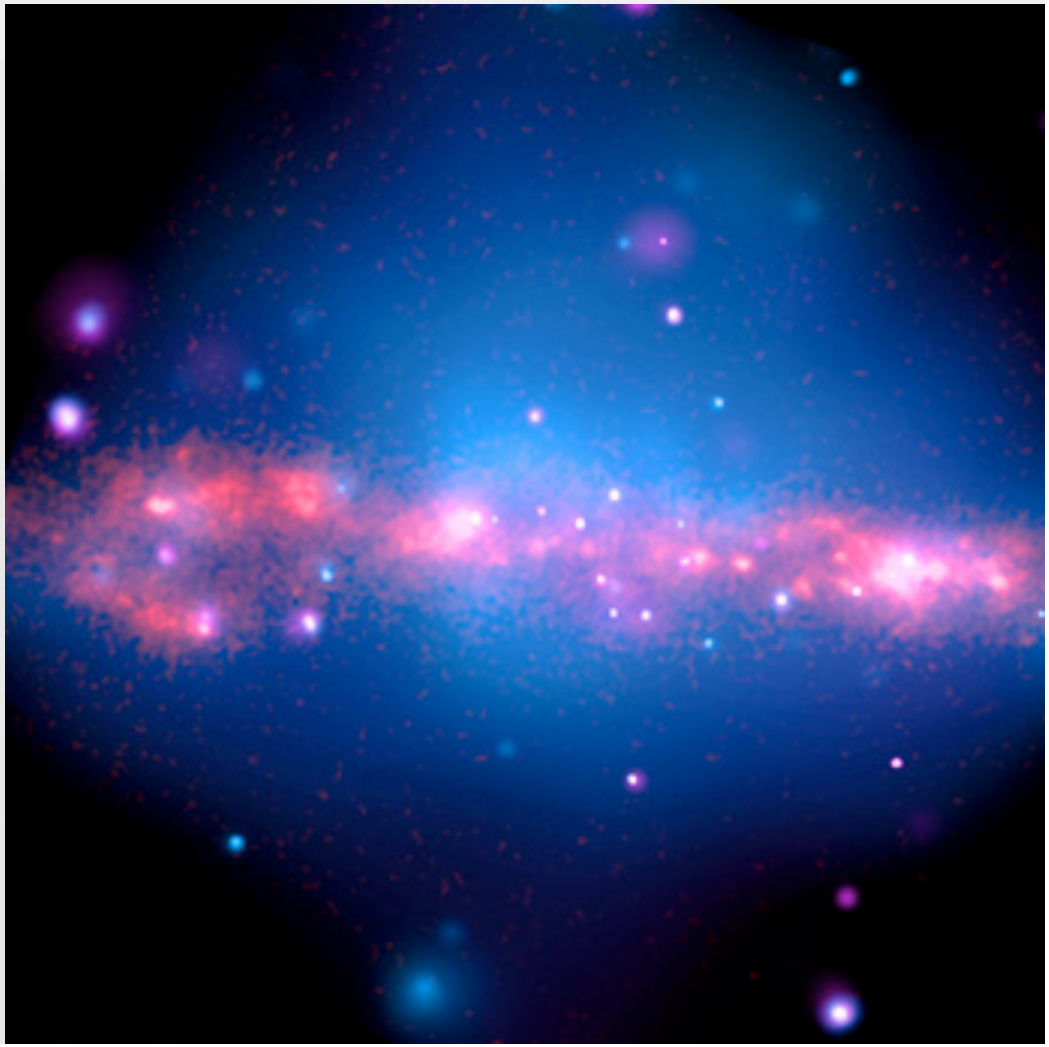
e.g., Tumlinson et al. 2011; Prochaska et al. 2011; Steidel et al. 2002; Putman et al. 2005; Chen et al. 2010; Penton et al. 2002; Bowen et al. etc.

Galaxy Gas Flows

- ✔ Is there cool gas beyond galaxies that will become star formation fuel?
- Is their a hot gaseous medium surrounding galaxies?

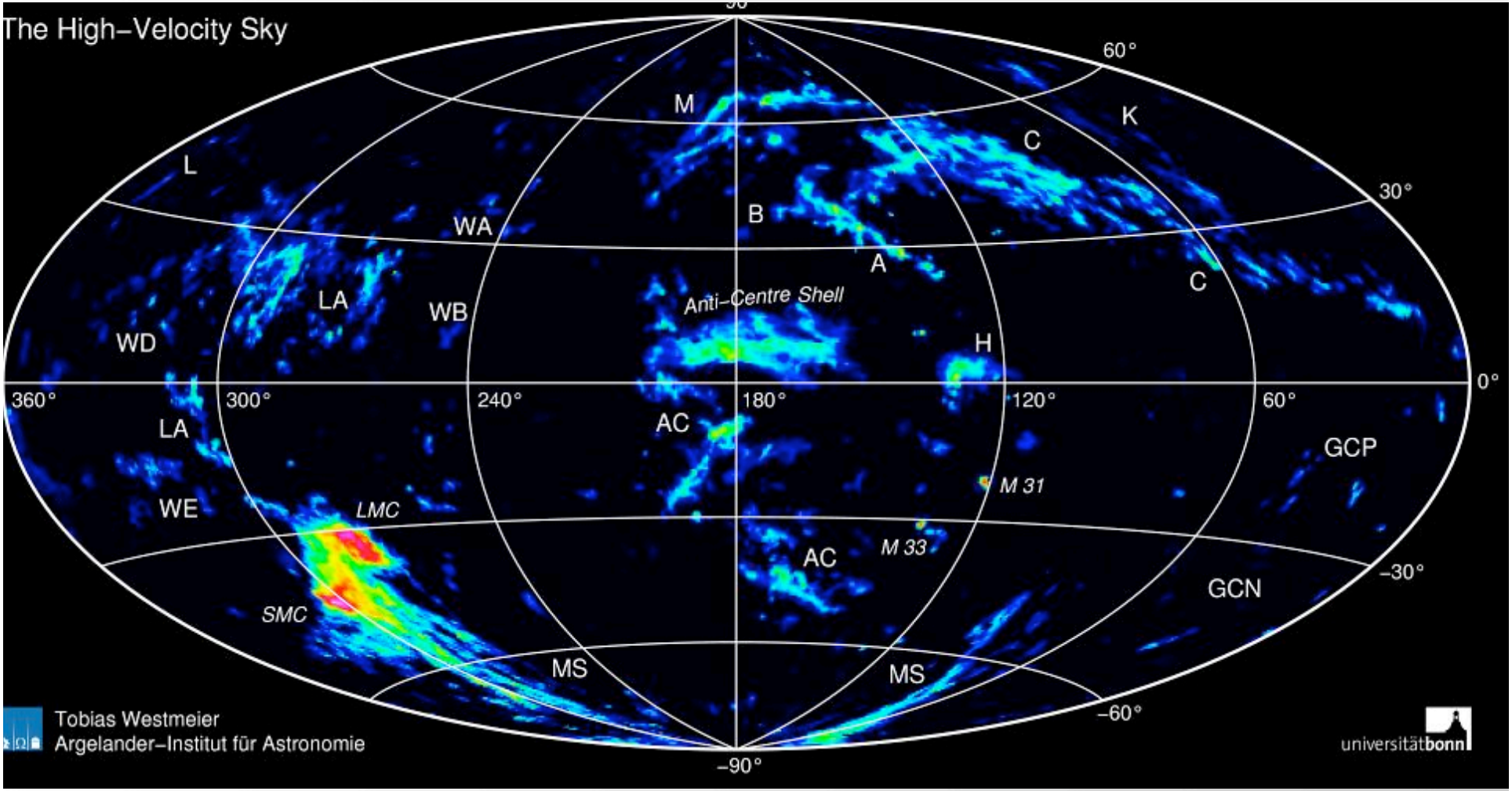
Hot halo gas

- Generally only detected directly within ~10 kpc of disk

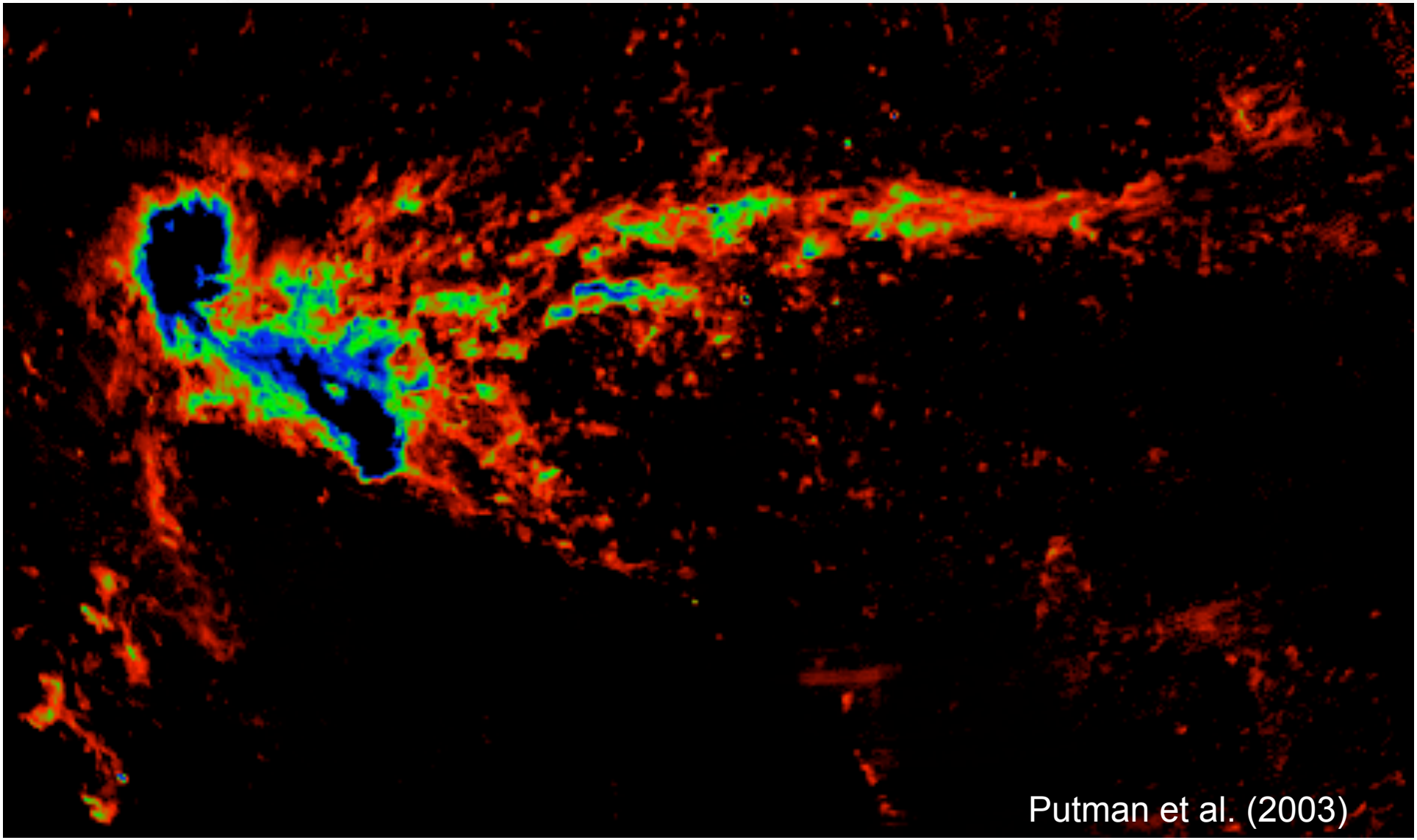


NGC 4631 (Chandra + HST; Wang et al.)

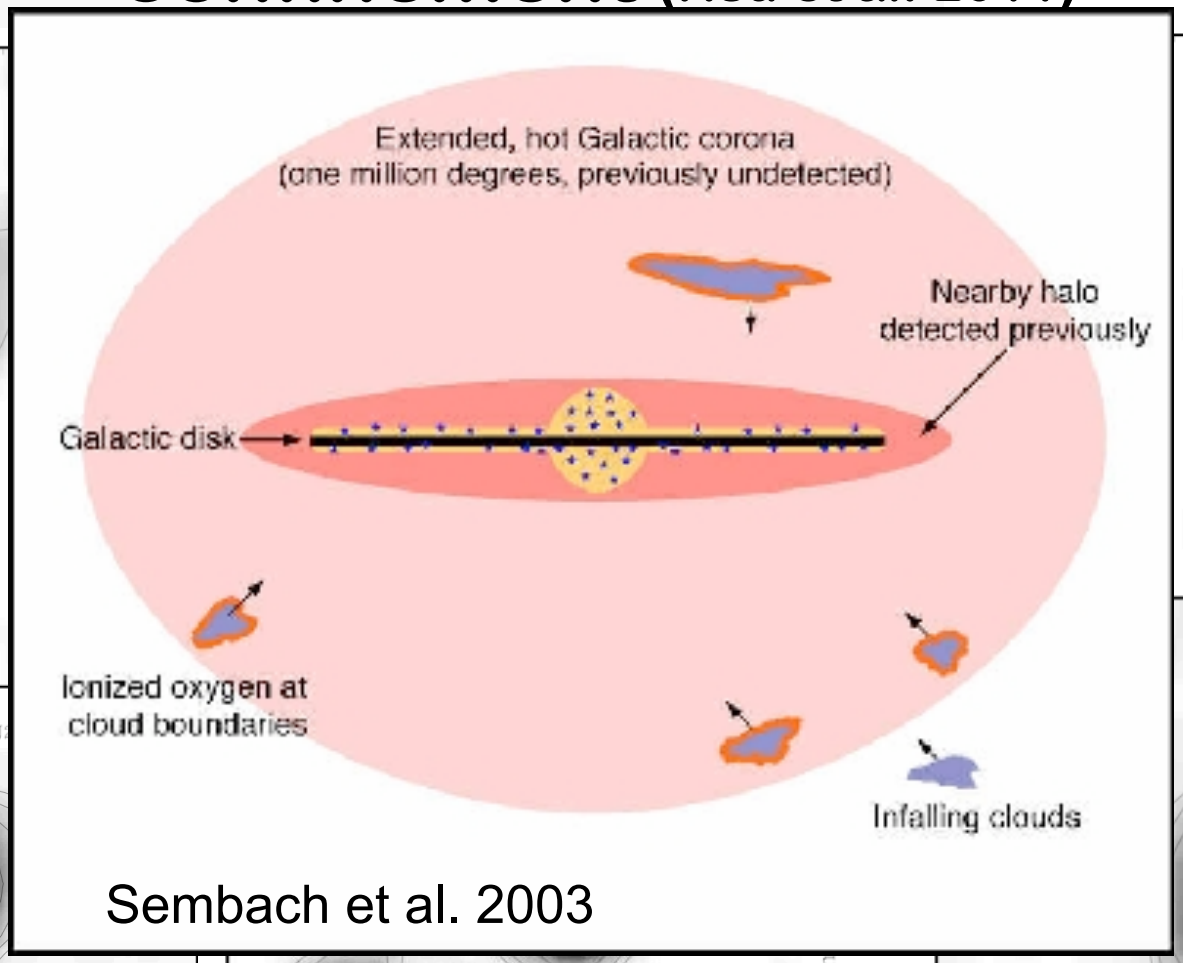
Cold Dense Halo Clouds Probe the Extended Hot Halo



✓ Magellanic System: Halo clouds at 50 – 100 kpc



Head-tail clouds, Halo OVI, and Pressure confinement (Hsu et al. 2011)



Sembach et al. 2003

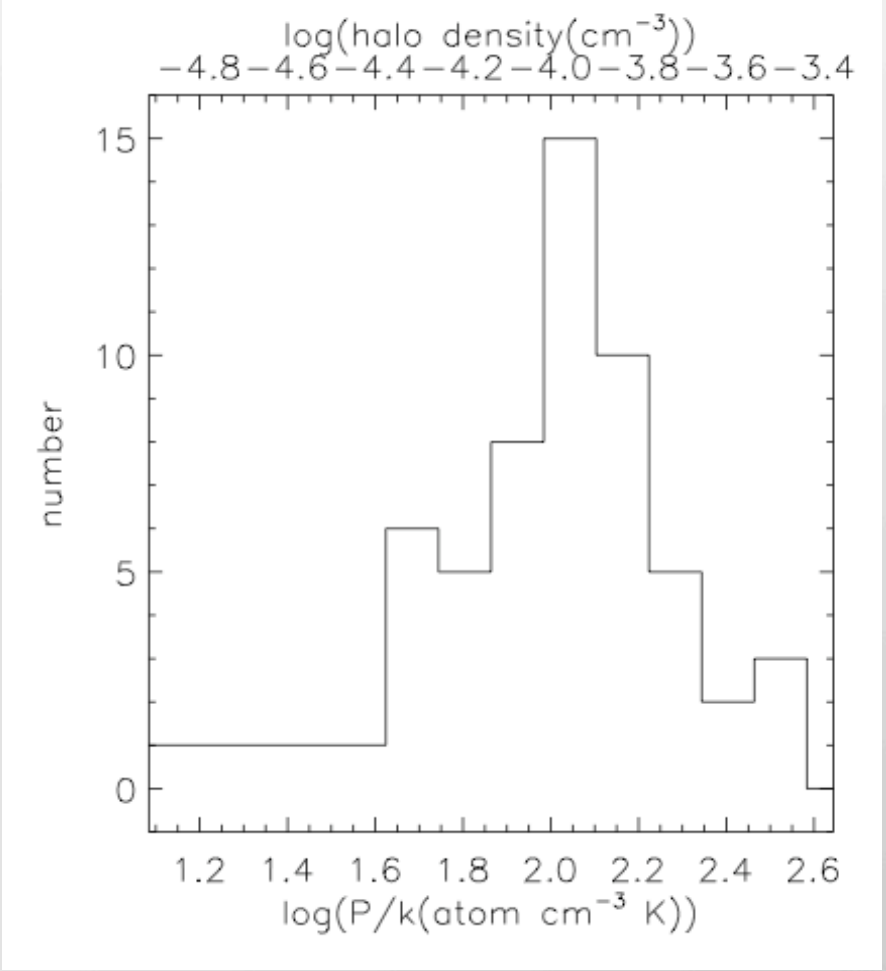
Putman, Saul, Mets (2011)

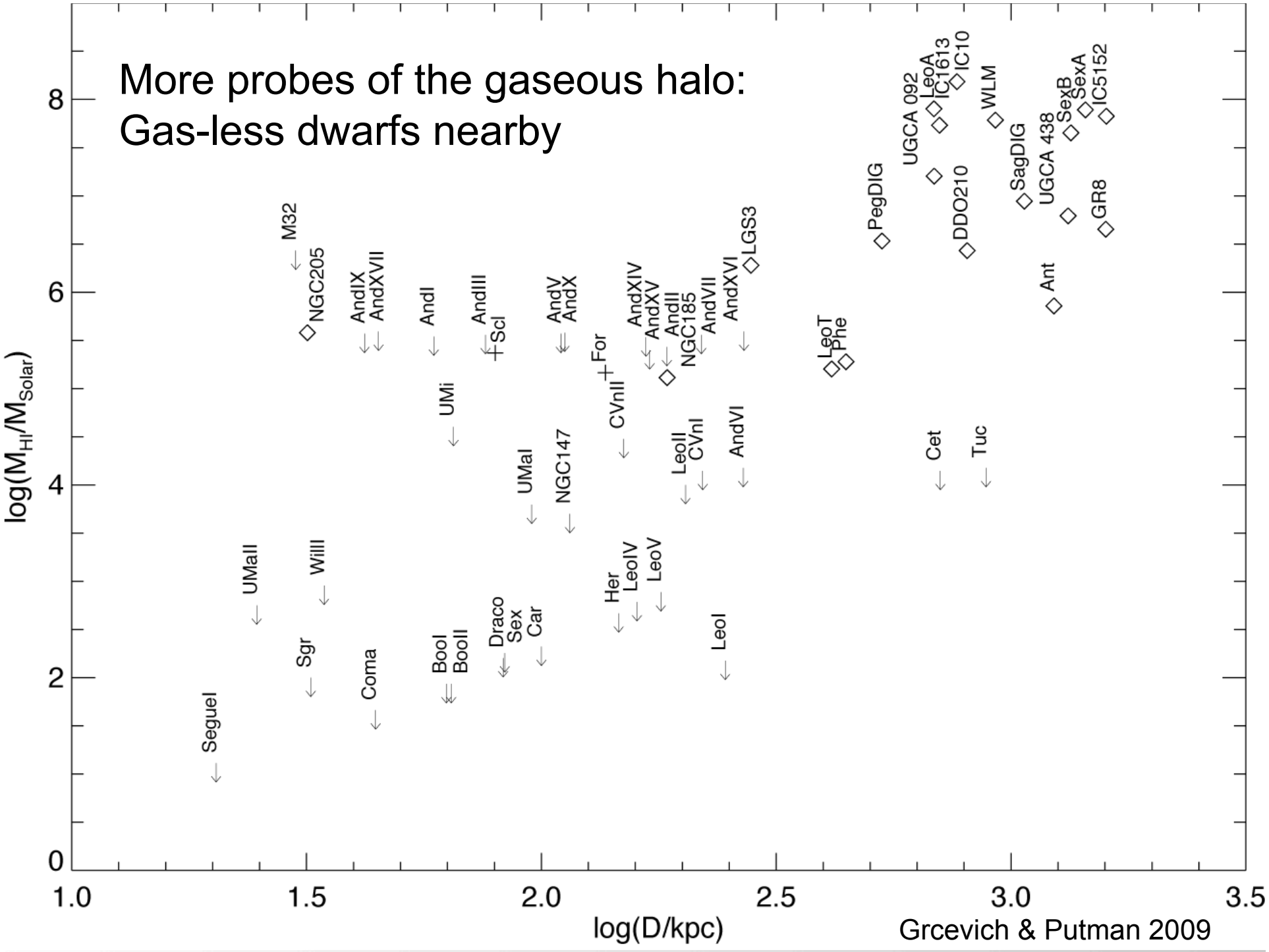
Clouds in the Magellanic Stream

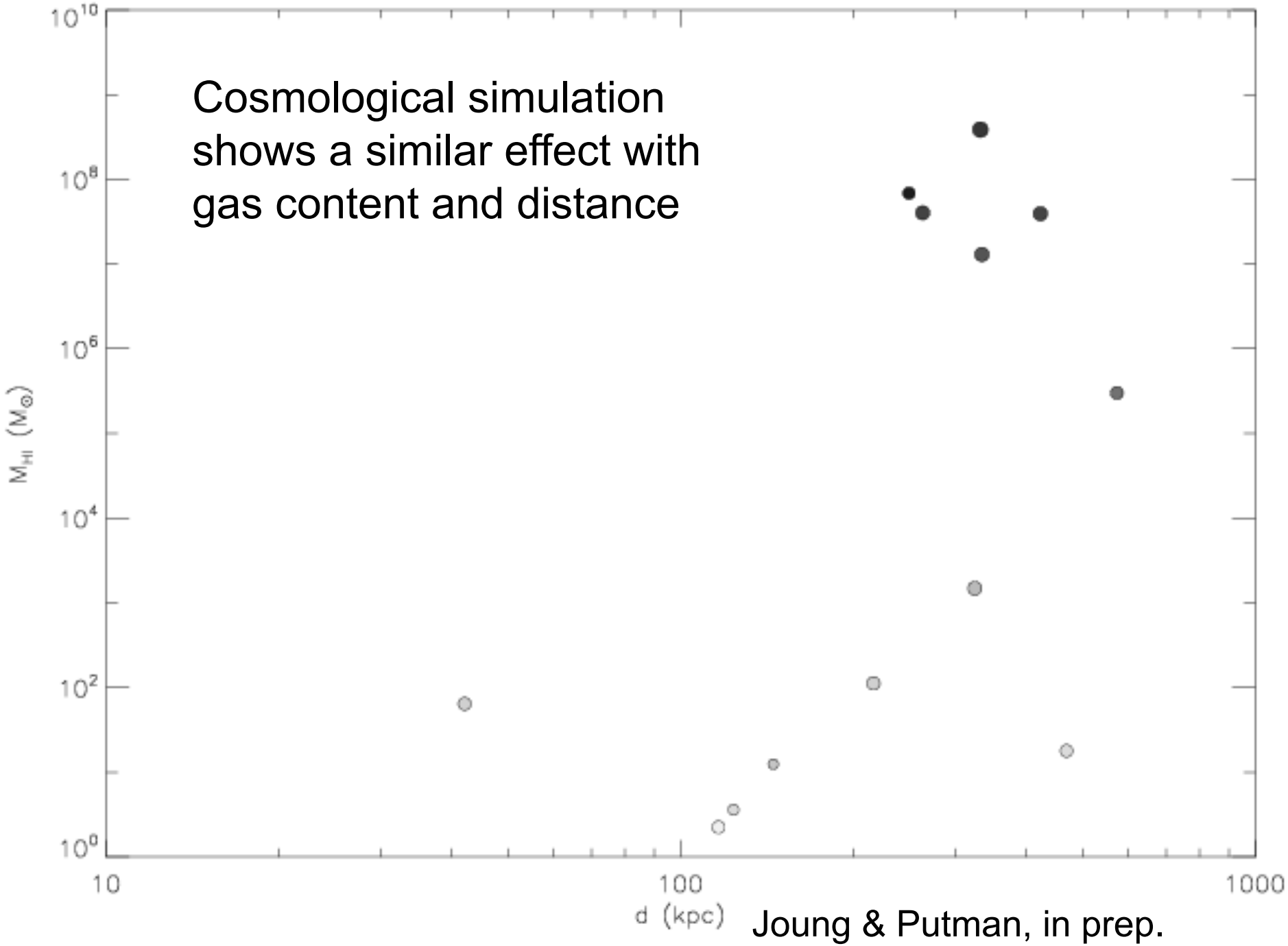
Halo density ~10^{-4} cm^{-3} at 60 kpc (~5 x 10^{-5} at 120 kpc)

Consistent within a factor of 3 with halo cloud simulations (Hsu et al. 2011)

In agreement with OVI halo model (Sembach et al. 2003)




More probes of the gaseous halo:
Gas-less dwarfs nearby
log(M_HI/M_Solar)
log(D/kpc)
0
2
4
6
8
1.0
1.5
2.0
2.5
3.0
3.5
M32
NGC205
AndIX
AndXVII
AndI
AndIII
Scl
AndV
AndX
For
CVnII
AndXIV
AndXV
AndII
NGC185
AndVII
AndXVI
LGS3
PegDIG
UGCA 092
LeoA
IC1613
IC10
WLM
SagDIG
UGCA 438
SexB
SexA
IC5152
GR8
DDO210
Ant
LeoT
Phe
UMi
UMaI
NGC147
Her
LeoIV
LeoV
LeoII
CVnI
AndVI
Cet
Tuc
Leo I
UMaII
WilI
Sgr
Coma
Bool
BooII
Draco
Sex
Car
Segue I
Grcevich & Putman 2009



Joung & Putman, in prep.

Galaxy Gas Flows

- ✔ Is there cool gas beyond galaxies that will become star formation fuel?
- ✔ Is their a hot gaseous medium surrounding galaxies?

Principal components are present
(detailed properties still under study)

Choose your own adventure?

1. Role of the hot halo in fueling vs. cold flow/satellite material
2. Gas getting directly into the star forming disk
3. Alternative fueling sources
4. Accretion as part of disk mixing and flat metallicity gradients (e.g., Werk et al. 2011)

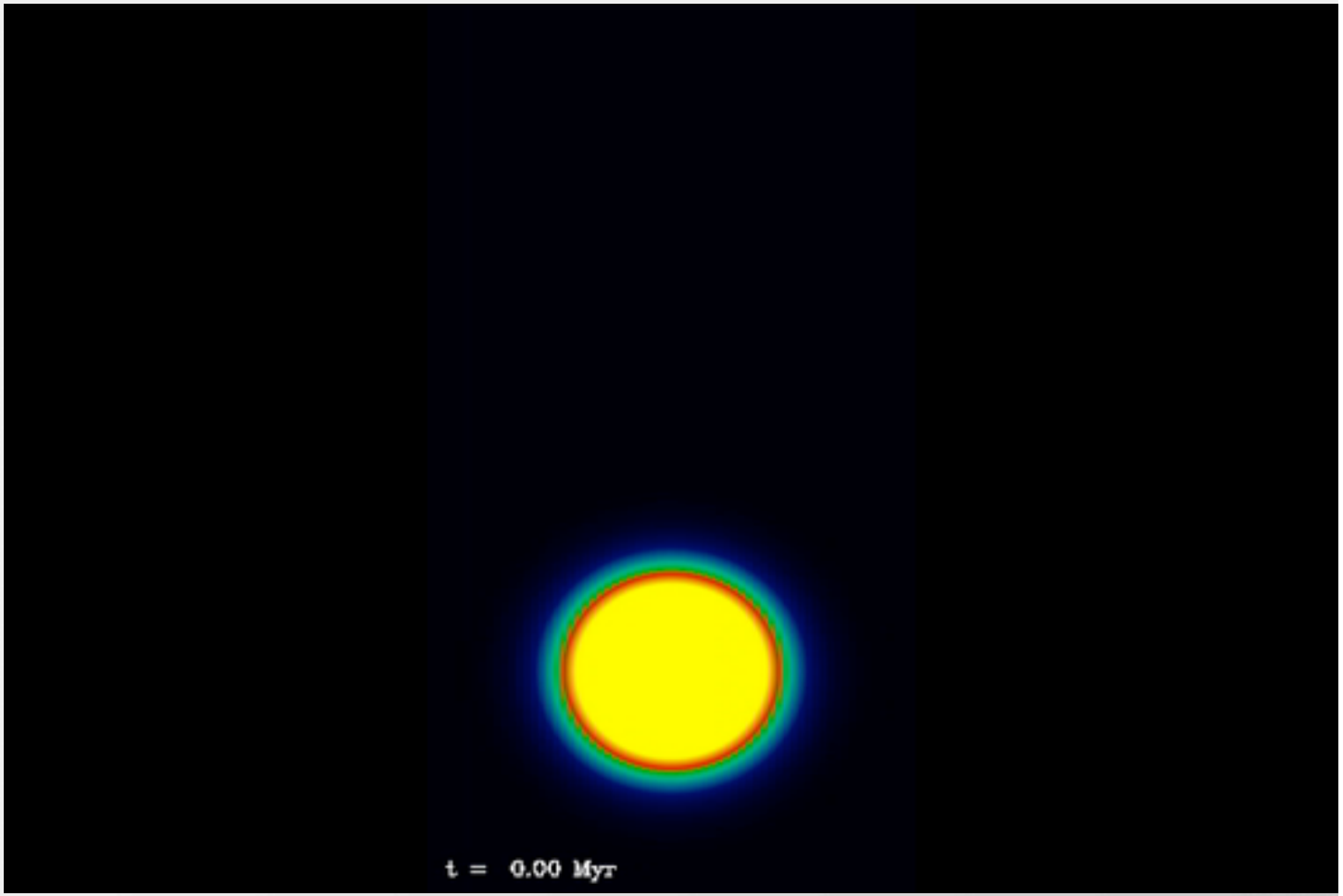
Cooling out of the hot halo?

- Linear perturbations don't work (e.g., Binney et al. 2009)
- But non-linear perturbations w/ overdensities > 10 begin to cool (Joung, Bryan & Putman 2011)
  - i.e. hope for incoming cool flows (e.g., Keres & Hernquist) or remnants of destroyed cold clouds

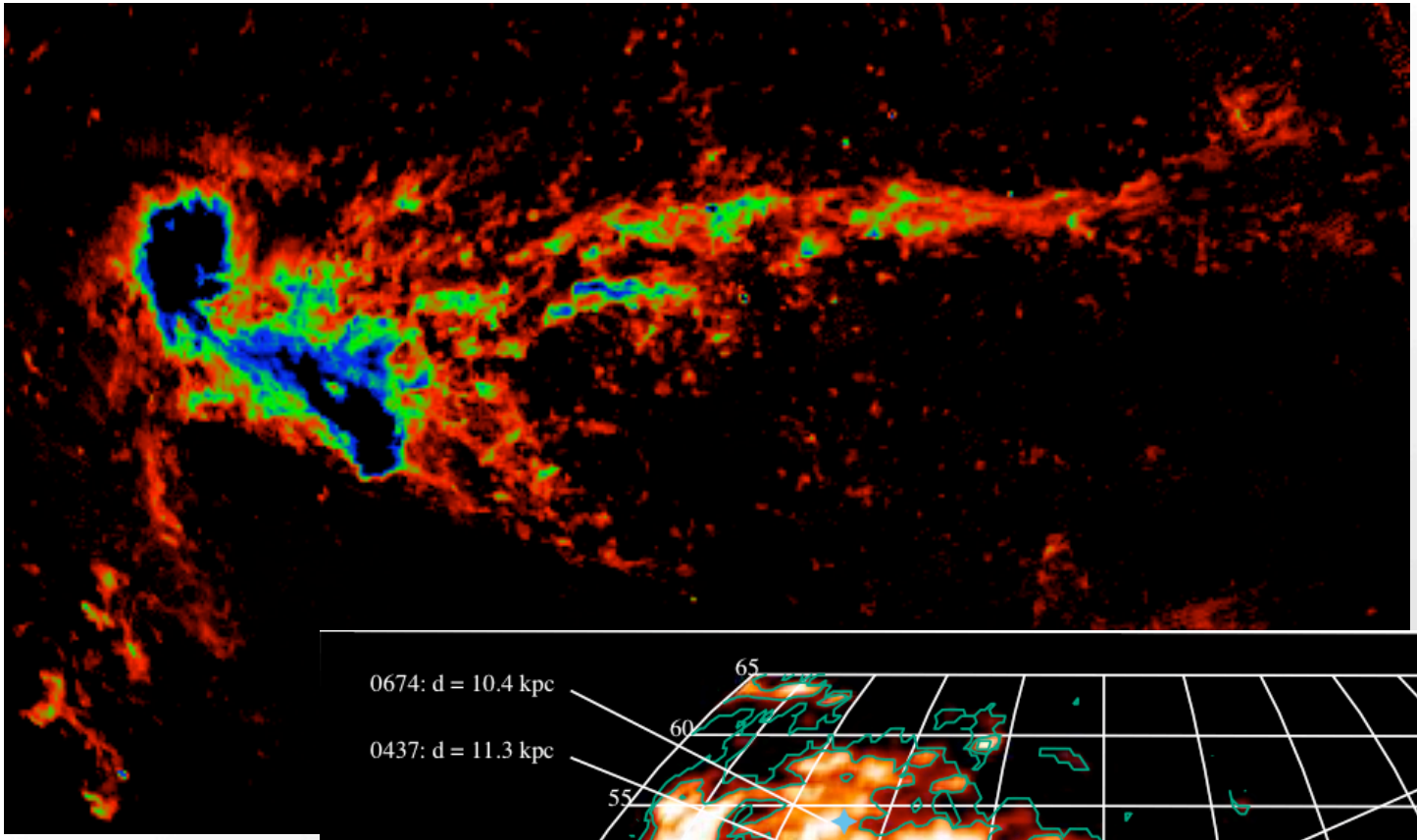
Cold Clouds from Cold Flows or Stripped Gas from Satellites

WILL THE GAS MAKE IT TO THE DISK?

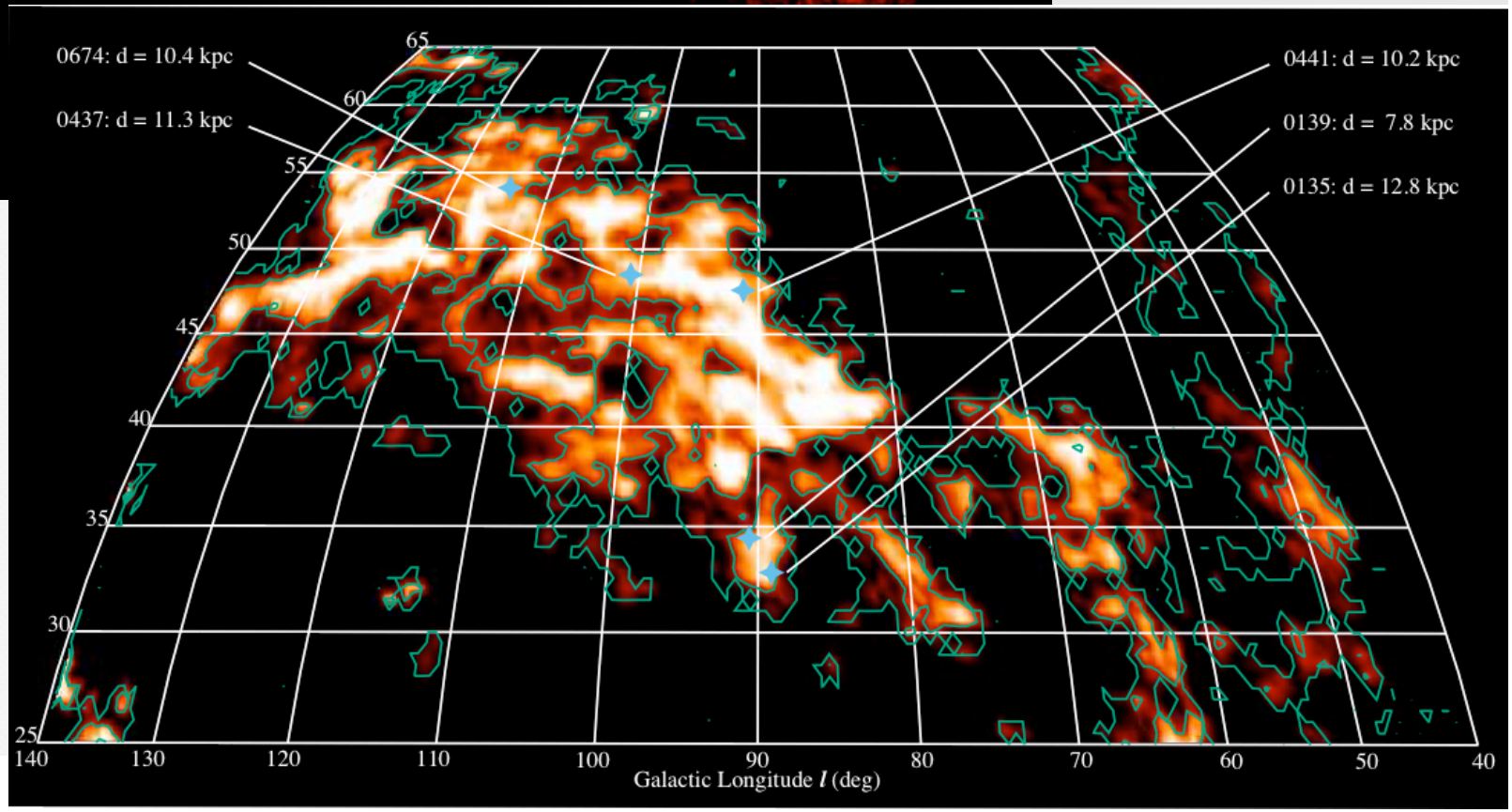
Typical halo clouds will travel < 10 kpc and be gone within 60 Myrs



(Heitsch & Putman 2009; also Bland-Hawthorn et al. 2007)

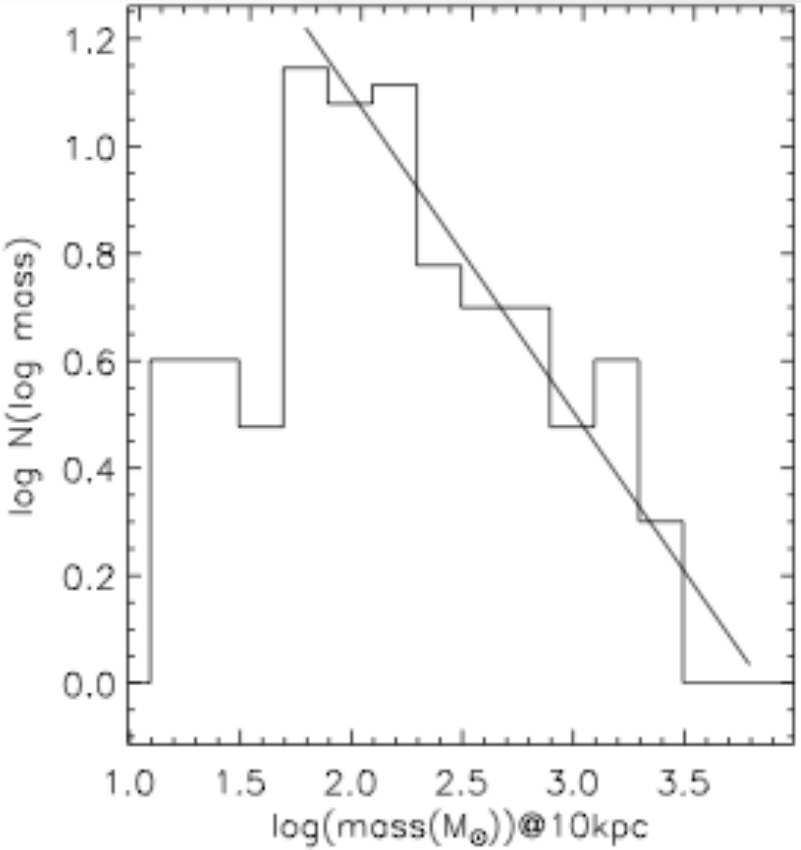


Coming in as massive blobs?

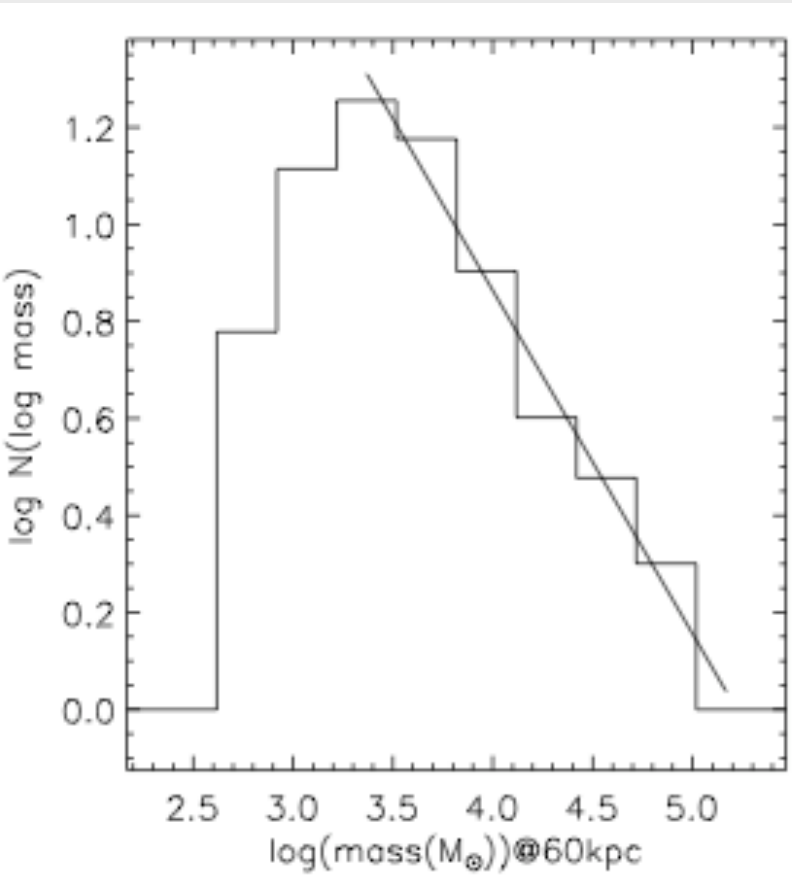


Large clouds are found to break into complexes of smaller clouds

Complex C (10 kpc)
(Hsu et al. 2011)

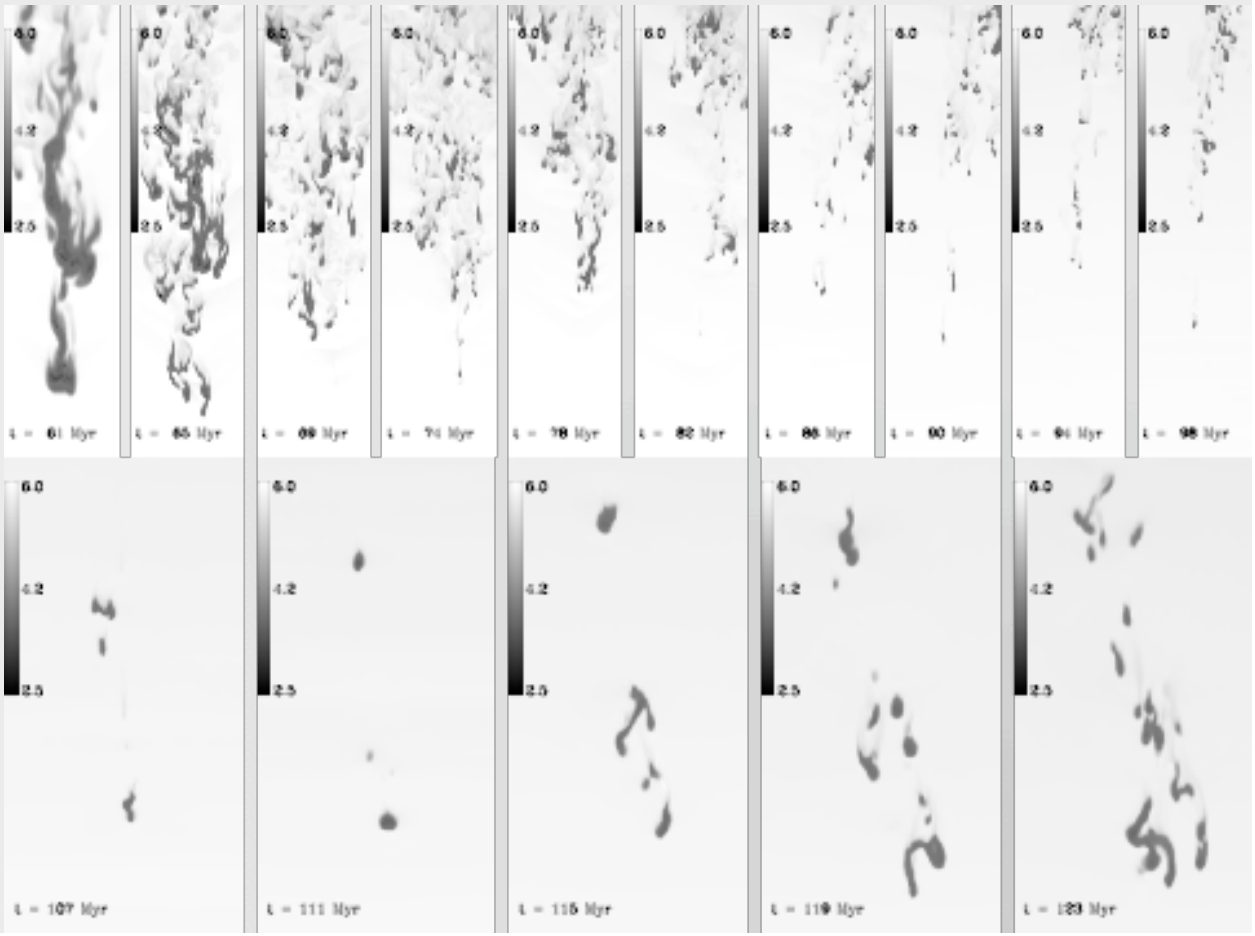


Magellanic Stream (~60 kpc)



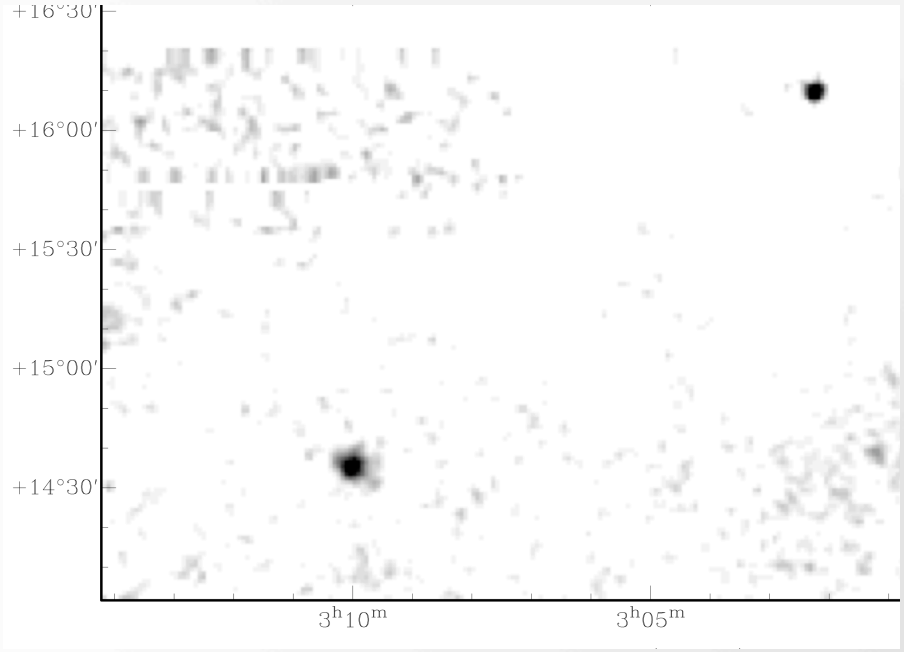
How do you feed the disk?

- Leftover density enhancements at the disk-halo interface slow and re-cool
- Expect a population of cold clouds rotating with the lower halo



(Heitsch & Putman 2009)

Observations of the disk-halo interface

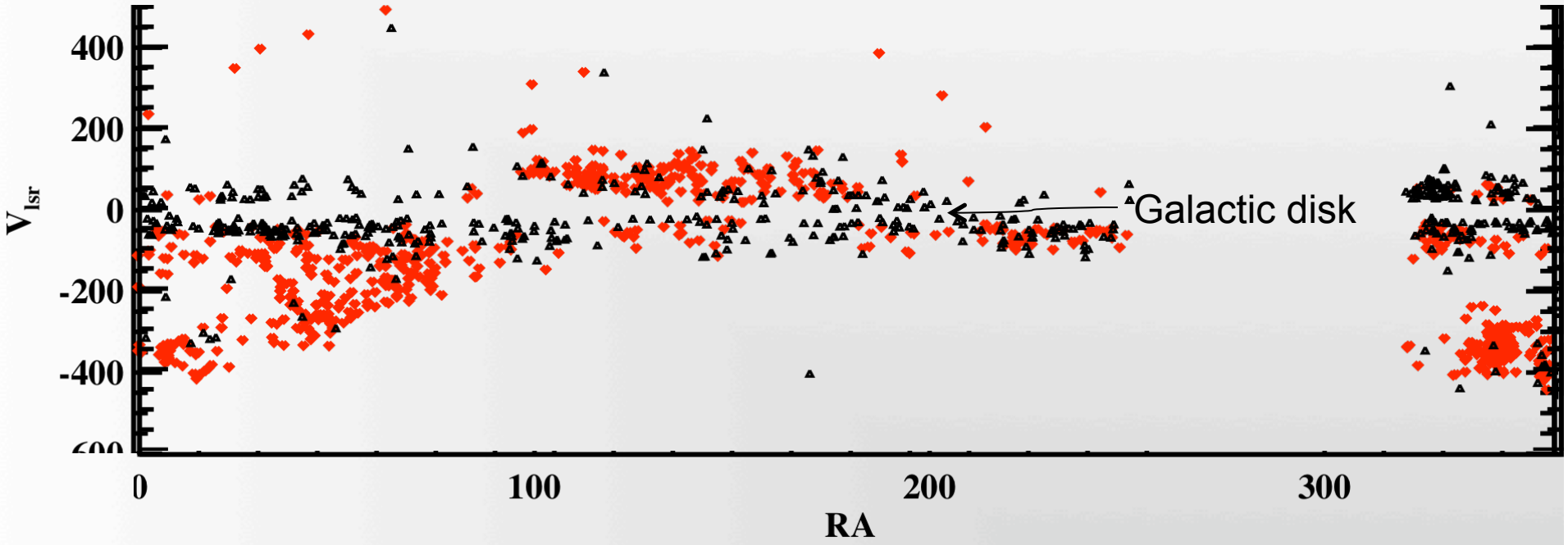


Relatively isolated, 0.1-1 M_{sun} at 1 kpc
(Saul et al. 2011; Begum et al. 2010)

GALFA-HI Survey data:

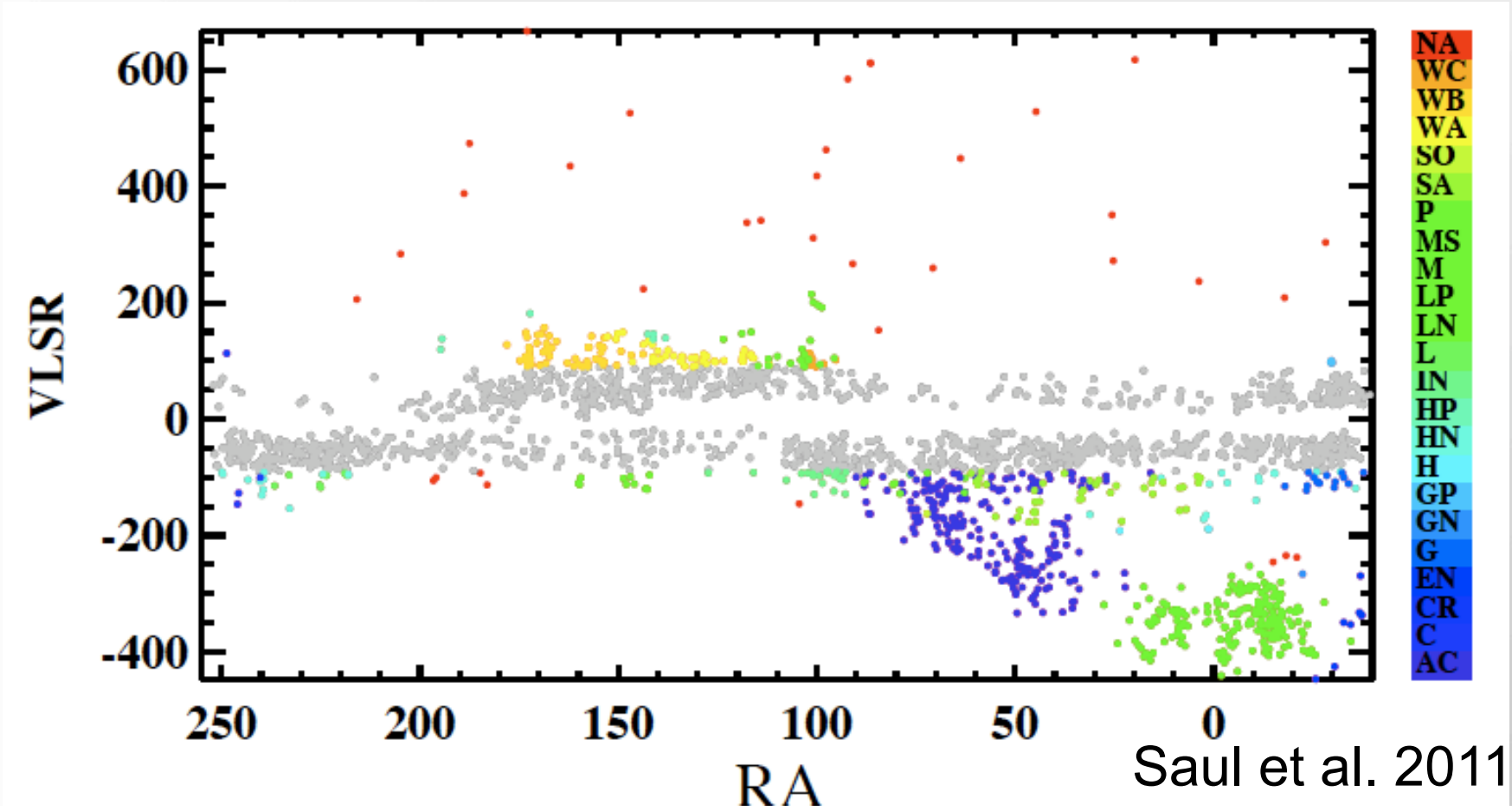
4’ and 180 **m**/s resolution (Peek et al. 2010)

Cooling at the disk?



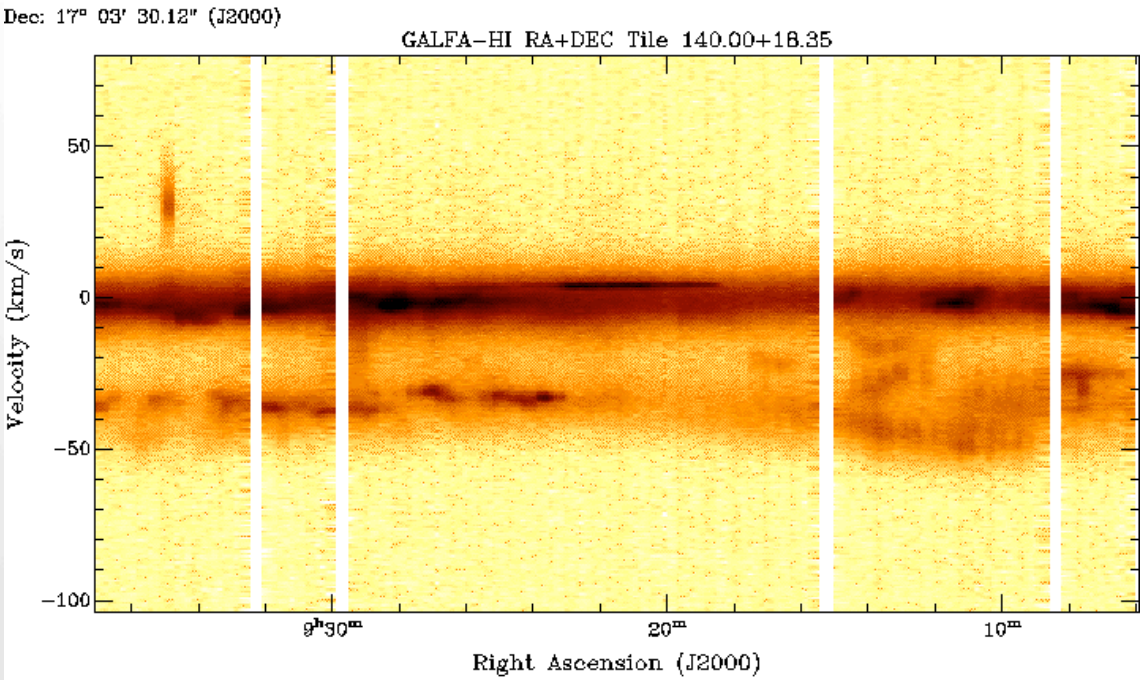
- **Cold clouds (black; < 5000 K) symmetric about Galaxy in velocity** (Saul et al. 2011; see also Lockman 2002; Stanimirovic et al. 2006; Ford et al. 2008)
- **Warm clouds (red; ~10,000 K) largely trace infalling/non-rotating halo features or galaxies**

Shreds of HVCs (color coded by Wakker-named HVC complex) and potential new galaxies (NA below and Grcevich et al. 2011)

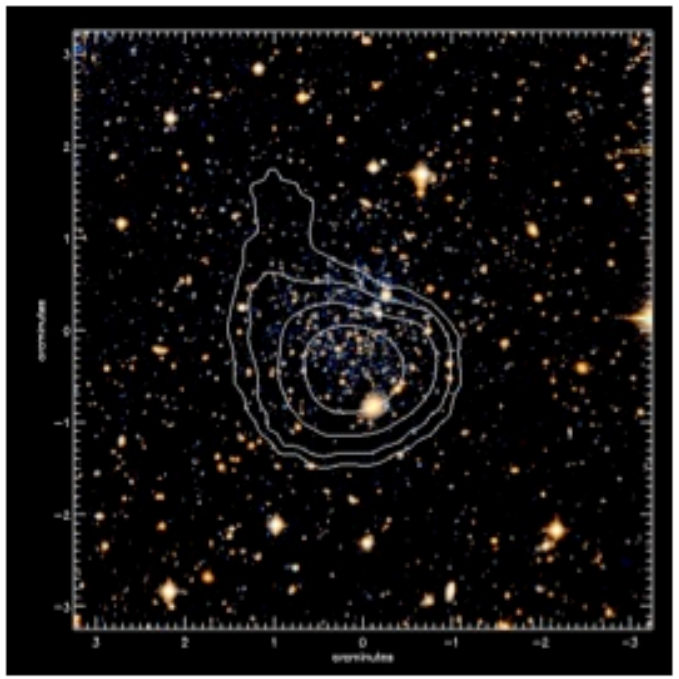


Saul et al. 2011

Potential New Dwarf Galaxies



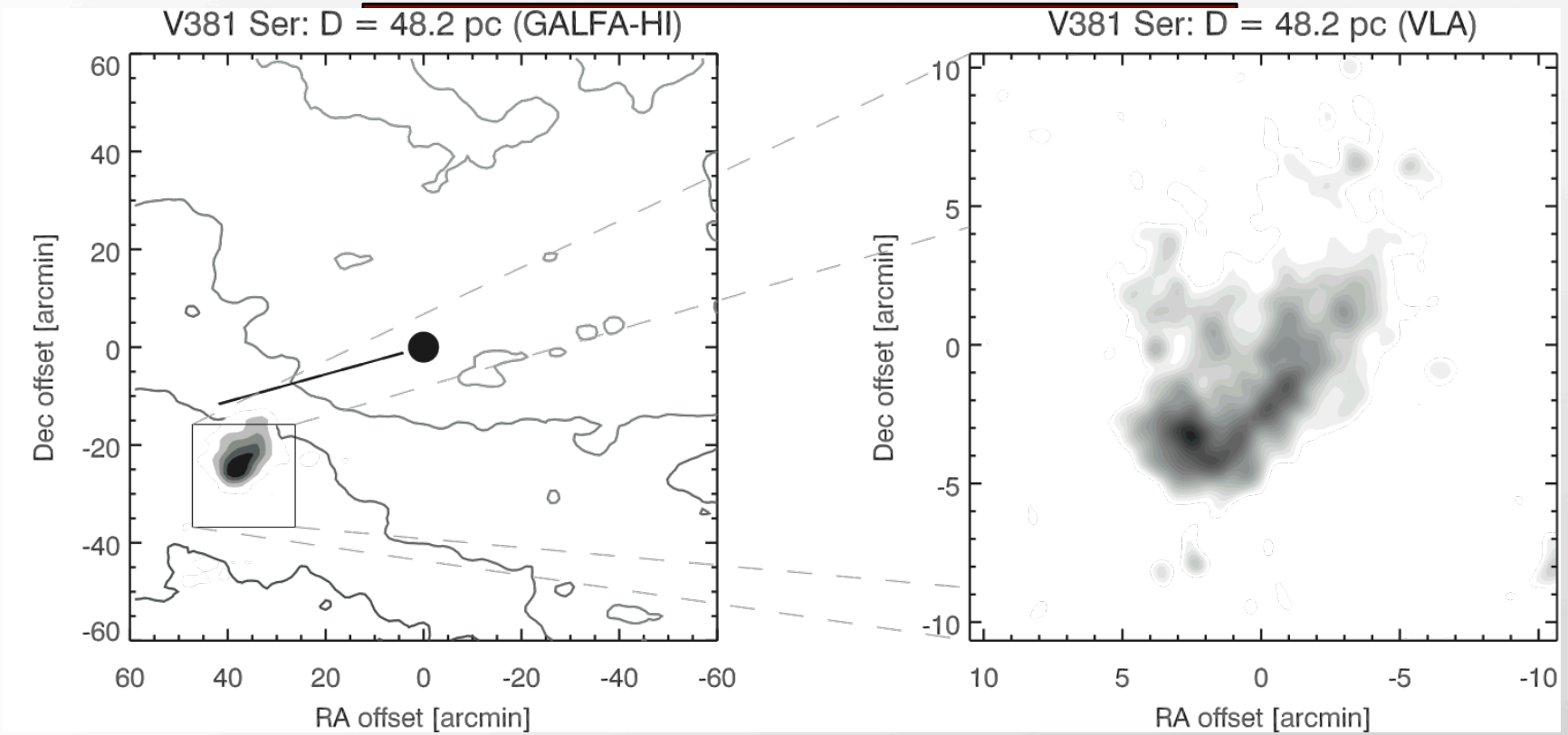
Only ~20 of 2000 clouds in mixed in velocity range show distinctly dwarf-like properties (Grcevich et al. 2011)



Leo T (Ryan-Weber et al. 2008)

Figure 1. Colour image of Leo T from INT WFC g and r band data with GMRT H I contours overlaid. The column density contours at 2, 5, 10 and 20×10^{19}, and the beam size is $39'' \times 47''$.

Still not enough fuel? Stellar Feedback



Small dusty cloud with large velocity gradient
Multiple cases of compact clouds near Mira variable stars in survey

Potentially and important neglected fueling source? (e.g. Leitner & Kravtsov 2011)

GALFA-HI Survey

All Arecibo Sky 13,000 deg^2 (Decl ~ +0 - 34)

Data released 6 months after cubes are made.

First release at:
https://purcell.ssl.berkeley.edu/
More info at:
http://sites.google.com/site/galfahi/

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Summary

- Evidence for both cold gas and an extended hot halo medium around galaxies
- Getting cold gas directly to the disk from cold flows and stripped satellites will be tricky (Heitsch & Putman 2009)
- Cooling out of hot halo also tricky, needs seeding (Joung, Bryan, Putman 2011)
- Large sample of discrete cold clouds using GALFA-HI (Saul et al. 2011):
  - cooling seeds at the disk-halo interface = ongoing 'quiet accretion'
  - Potential gas-rich LG dwarfs and stellar outflows (Grcevich et al. 2011)