GBT Observations of Extended HI around the THINGS galaxies

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GBT THINGS Survey Goals

- Provide total power HI data to combine with VLA data for studies of star formation in outer disks.
- Combined GBT+VLA data will improve sensitivity for studying the HI distribution and kinematics of outer disks.

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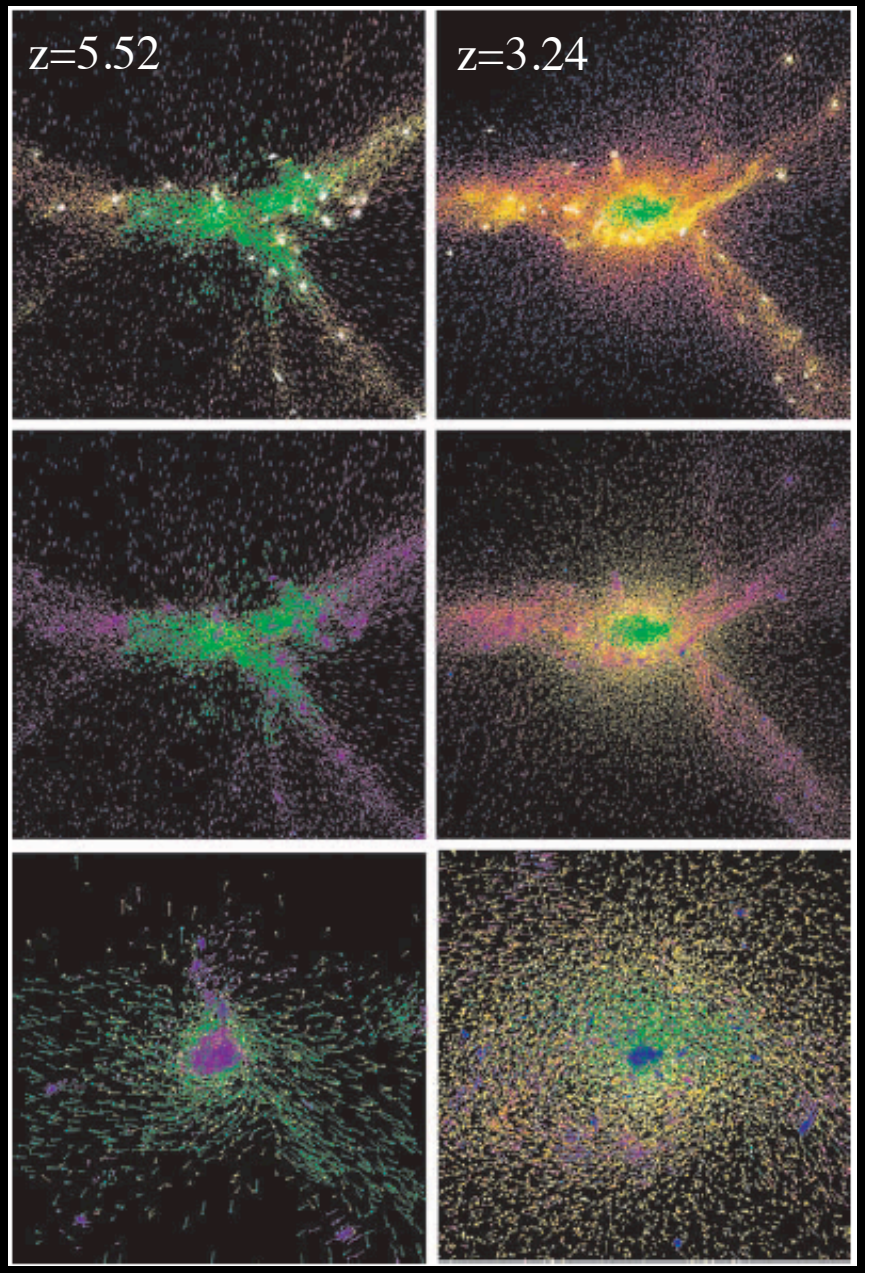
- Provide total power HI data to combine with VLA data for studies of star formation in outer disks.
- Combined GBT+VLA data will improve sensitivity for studying the HI distribution and kinematics of outer disks.
- Study the low column density HI environments of galaxies including identifying signatures of past tidal interactions and cold flows for galaxies with a range of masses, SFRs, and environments.

Hot/Cold Flows

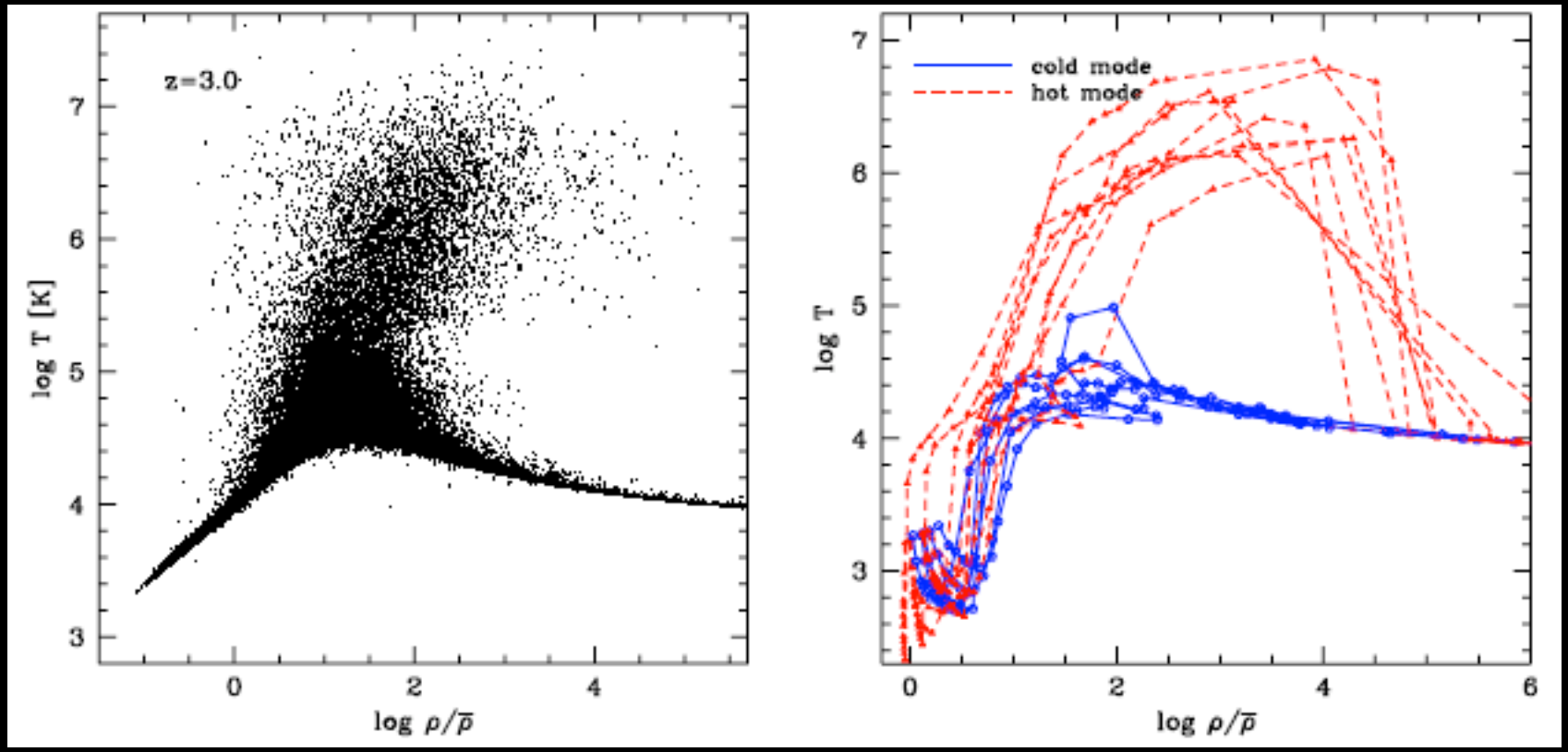
- Many simulations predict that gas is accreted by galaxies in two forms (e.g. Birnboim & Dekel 2003, Keres et al. 2005, 2009).
- Hot flows are gas that is shock-heated to the virial temperature; $T > 10^5$ K.
- Cold flows remain below T_{vir}, < 10^5 K, and falls onto galaxy along filaments.
- At z=0, cold mode should be dominant for $M_{halo} \leq 10^{11} M_{\odot}$ and in low density environments.



Keres et al. 2005

Tracing cold flows with HI

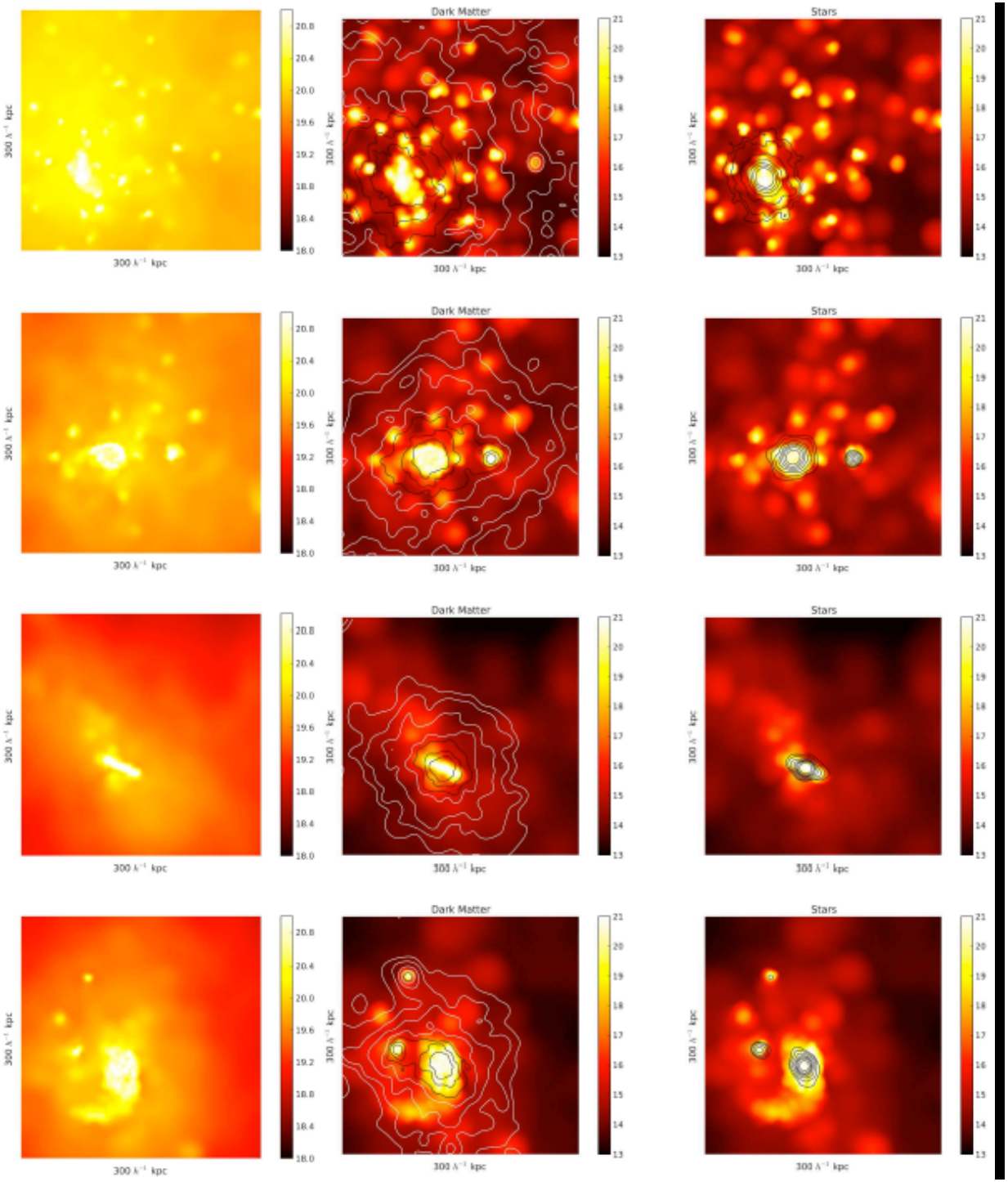
- HI emission traces cold flows over a range of densities at T ~ $10^{3\text{-}4}$ K.



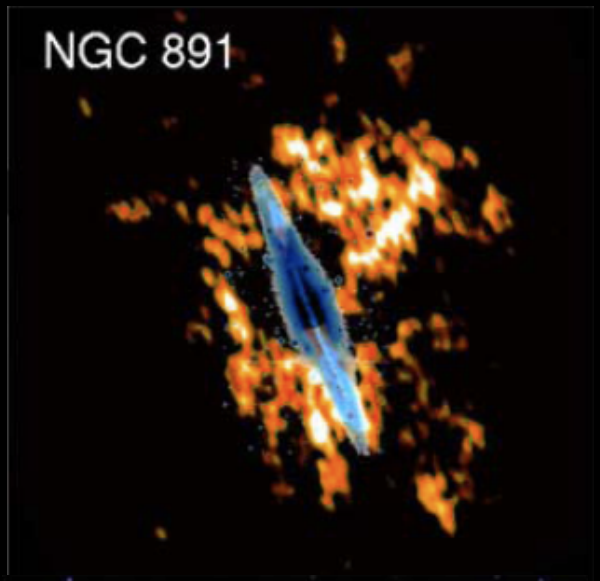
Hydrogen around galaxies

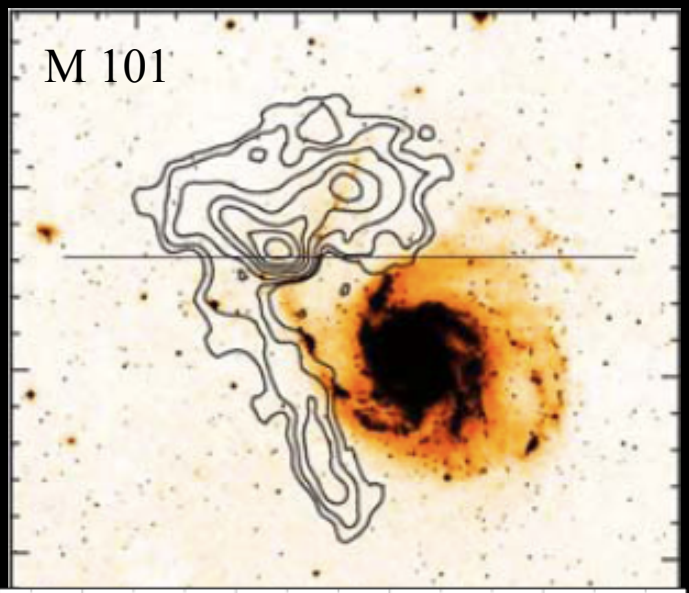
- Some of HI is condensed at high N_{HI}, the rest is diffuse with low N_{HI}.
- Low N_{HI} filaments have sizes of ~ 25 kpc.
- These HI filaments would be seen as Lyman limit systems in absorption.
- This HI can be detected in emission with current radio telescopes and sufficient time.

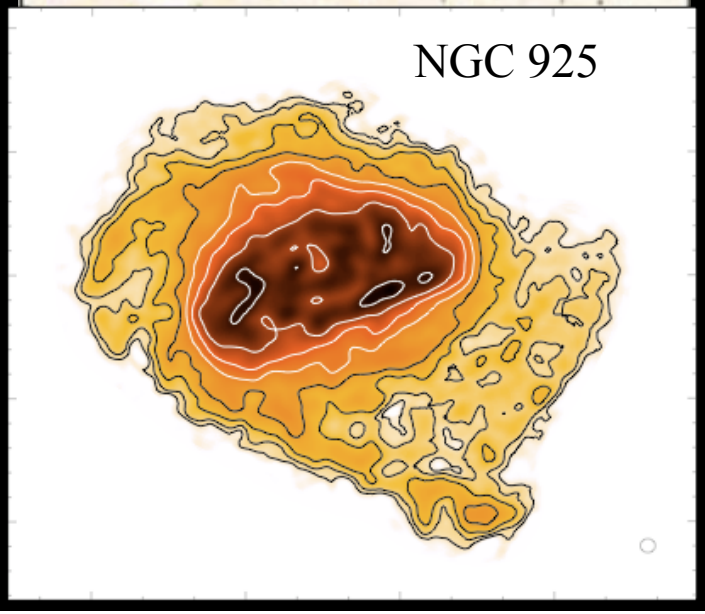
Popping et al. 2009



Ongoing accretion of gas onto nearby galaxies?



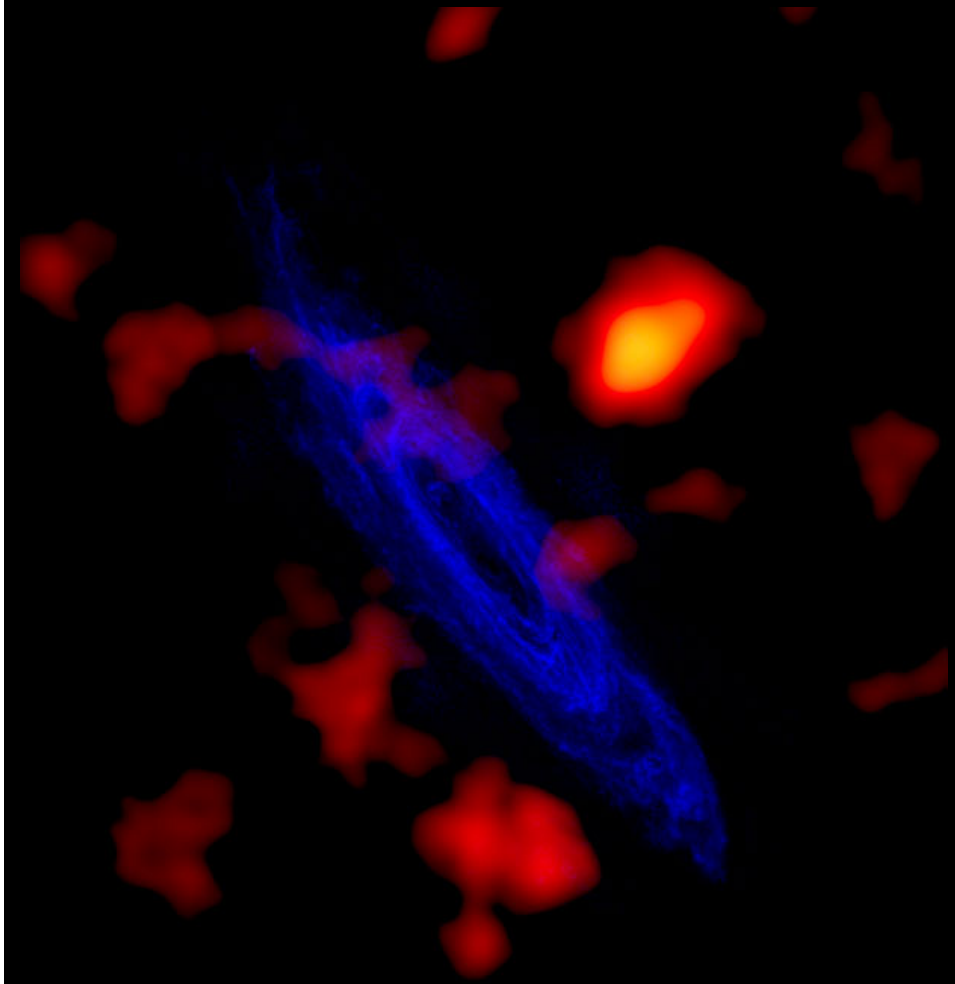


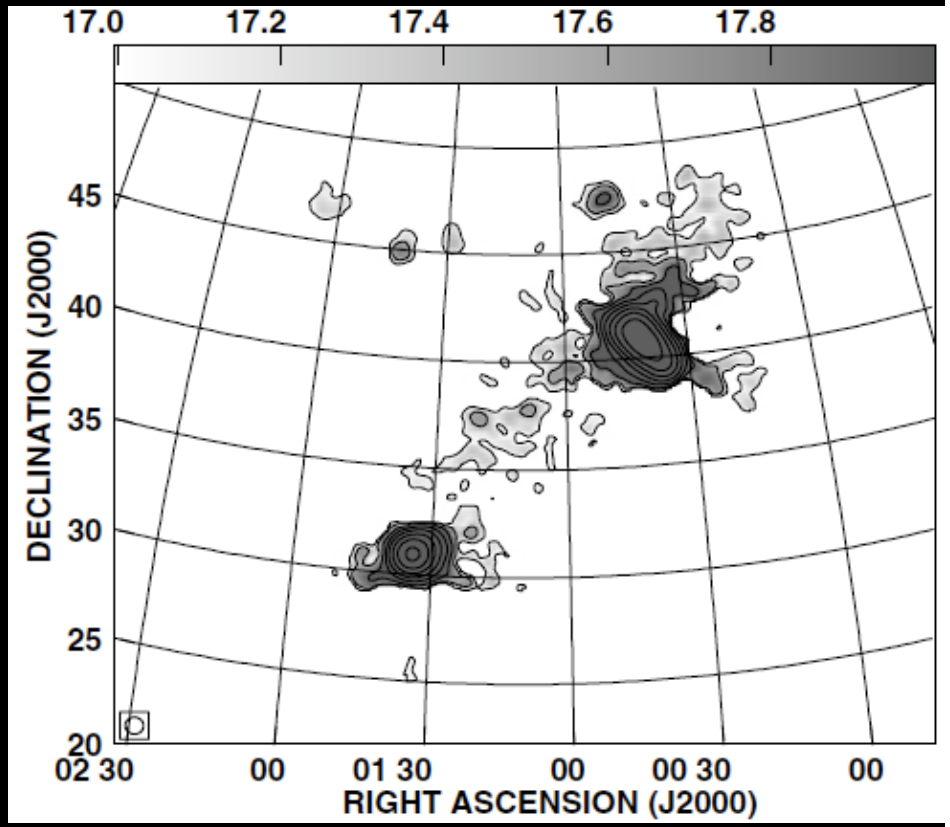


Sancisi et al. 2008

A HI bridge between M31 and M33

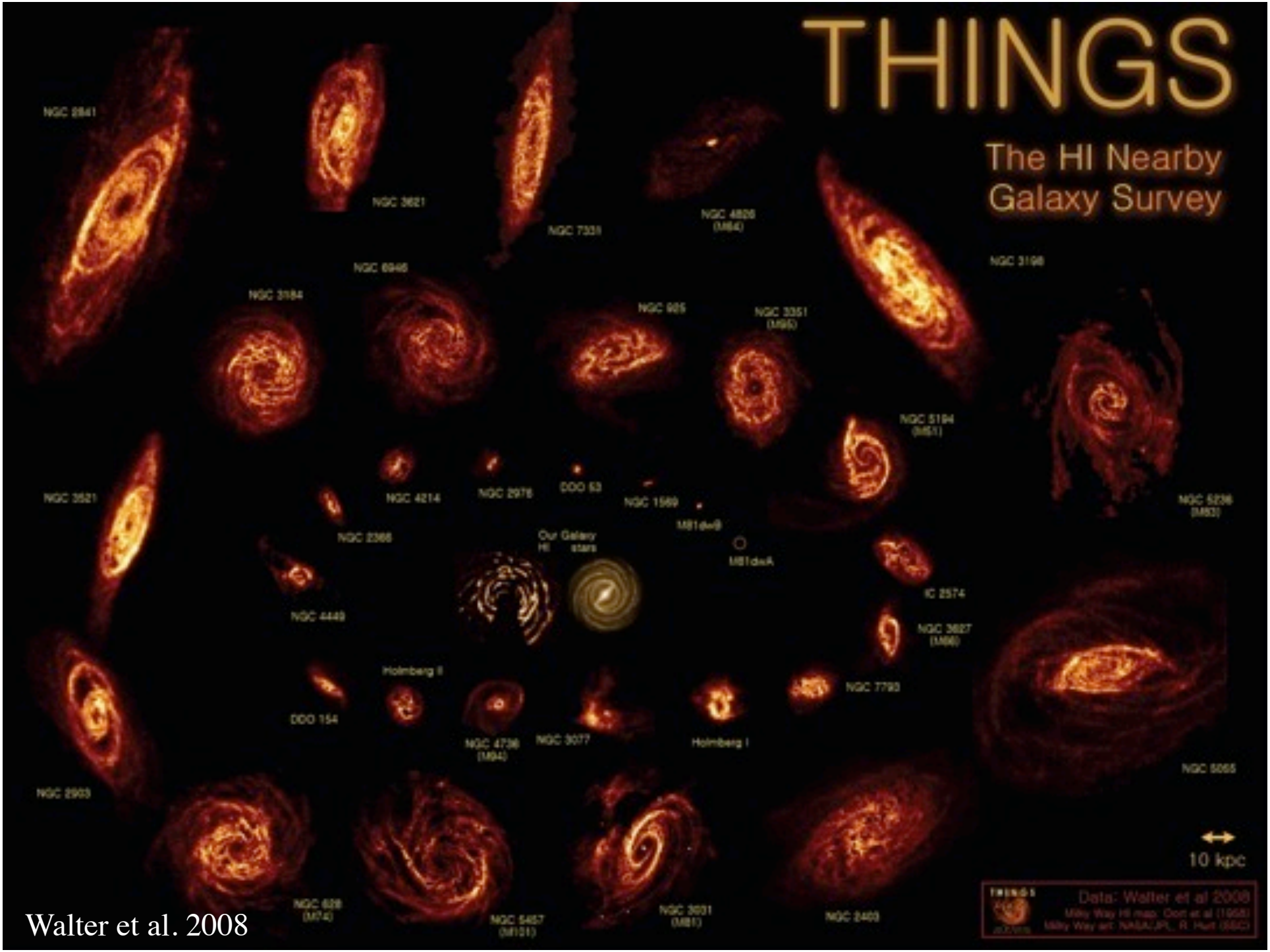
(see Lockman & Wolfe talk/poster)





$N_{HI} = 0.5 – 20 \times 10^{18}$ cm^{-2}

Thilker et al. 2004; Braun & Thilker 2004

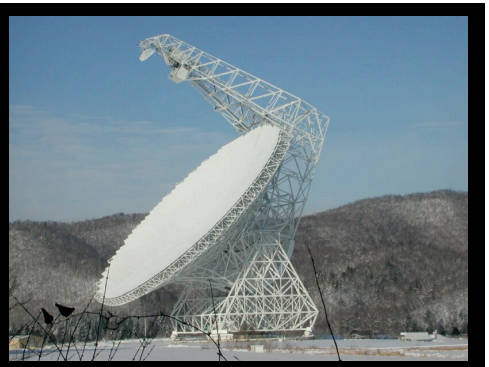


Walter et al. 2008

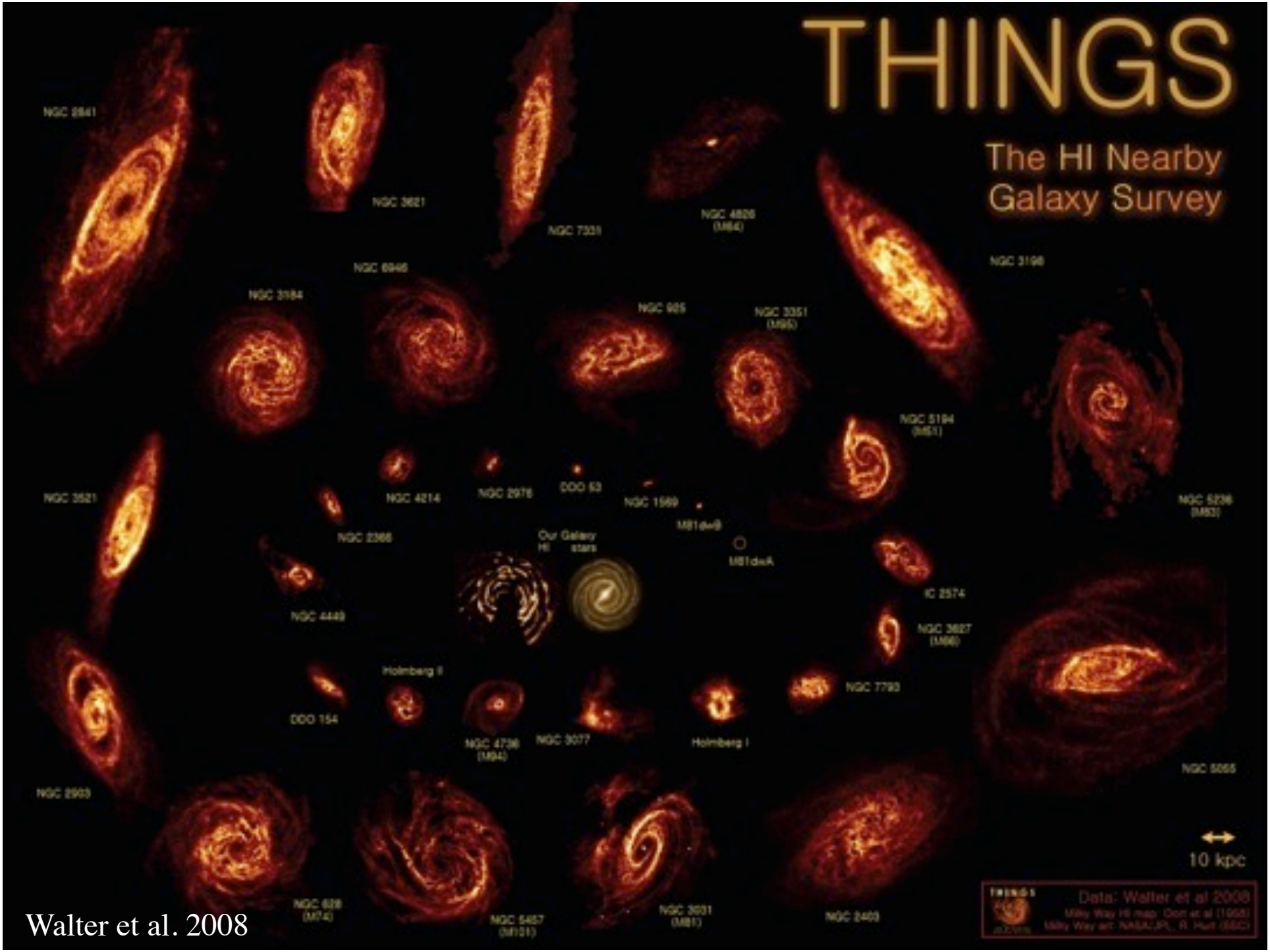
While THINGS VLA observations are excellent for studying the inner disks of galaxies at high resolution, they are insensitive to HI extended over large scales and at low column densities.

Single-dish observations are needed!

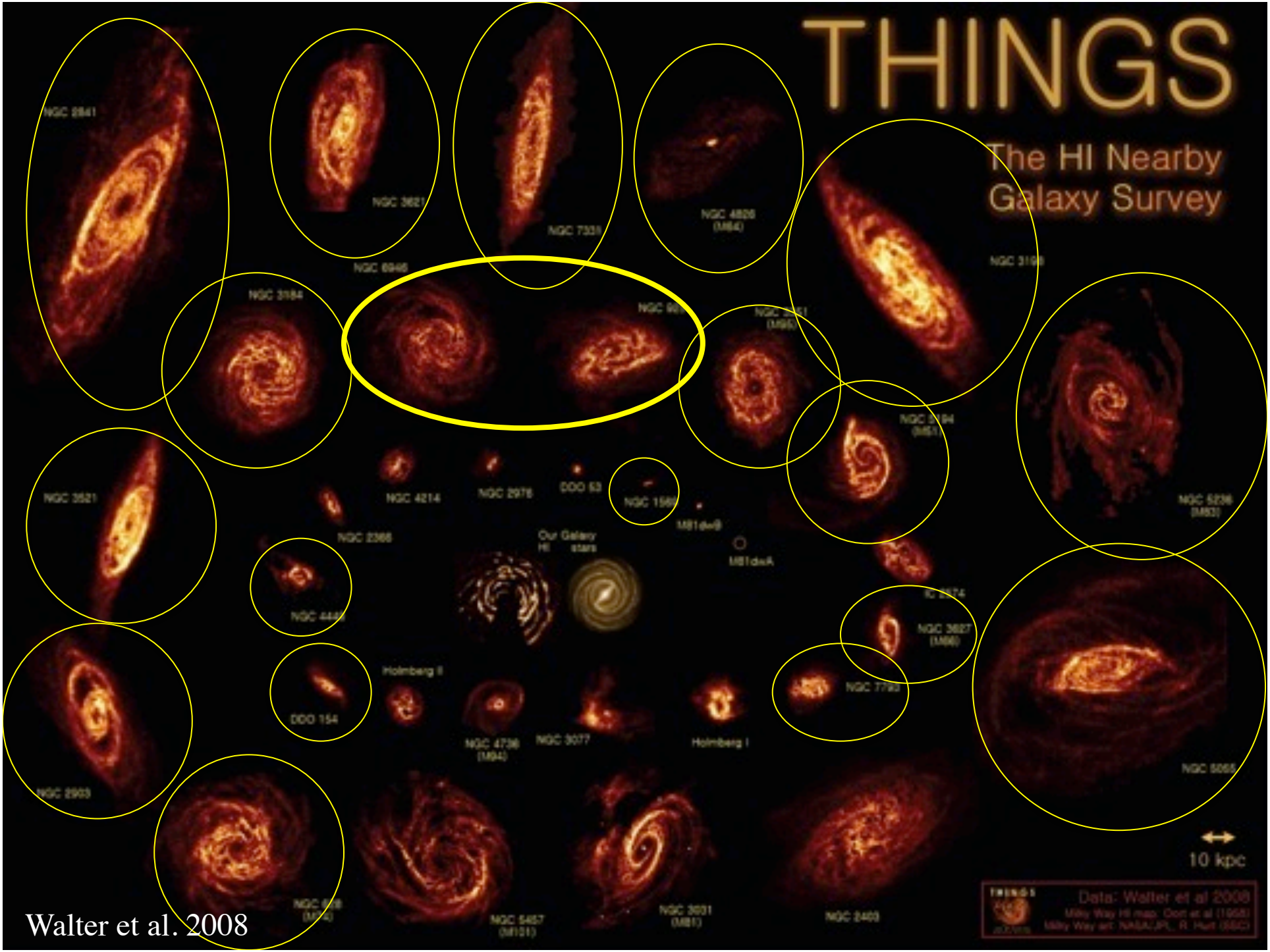
GBT Observations



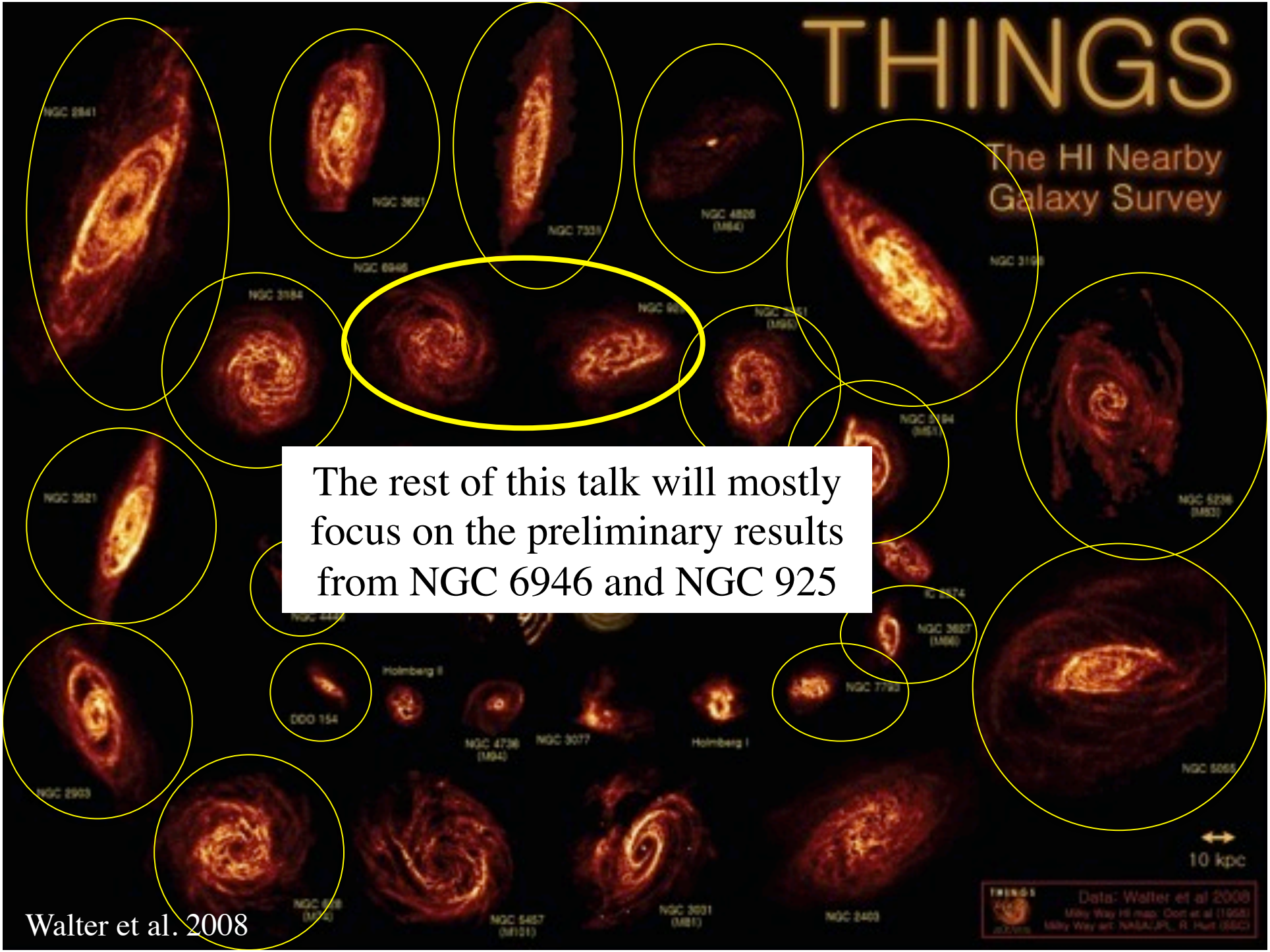
- Green Bank Telescope (GBT) has unmatched combination of sensitivity and resolution *as well as very low sidelobes!*
- Mapped 4 □° around 21 THINGS galaxies at 9.2' resolution between January-March 2011. THINGS galaxies at D = 2-15 Mpc.
  - maps are 70-513 kpc on a side depending on galaxy
  - 5-40 kpc beamsize depending on galaxy
- Spent 10 hours per galaxy for a rms sensitivity of ~20 mK per 5.2 km/s channel or 5σ, 20 km/s detection limit of $N_{HI} \sim 2 \times 10^{18}$ cm^{-2}.
- Data taken in frequency-switched mode, but can improve sensitivity by using edges of maps as "OFF" position.
- The remaining 13 galaxies have already been observed by Chynoweth et al. (2008, 2009).



Walter et al. 2008

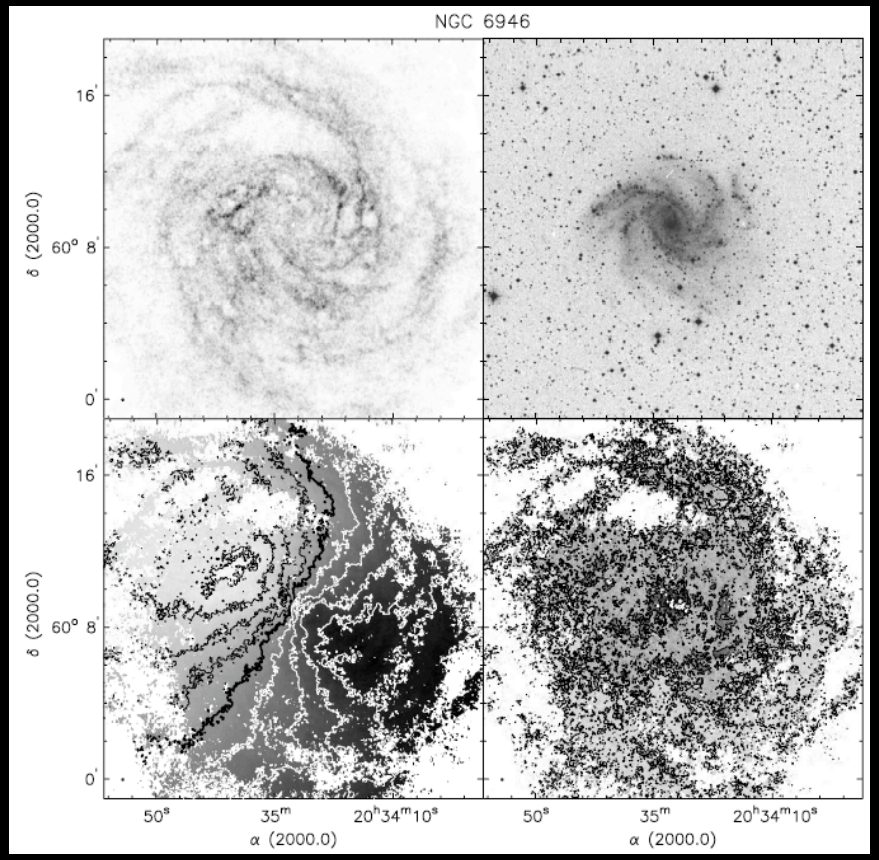


Walter et al. 2008

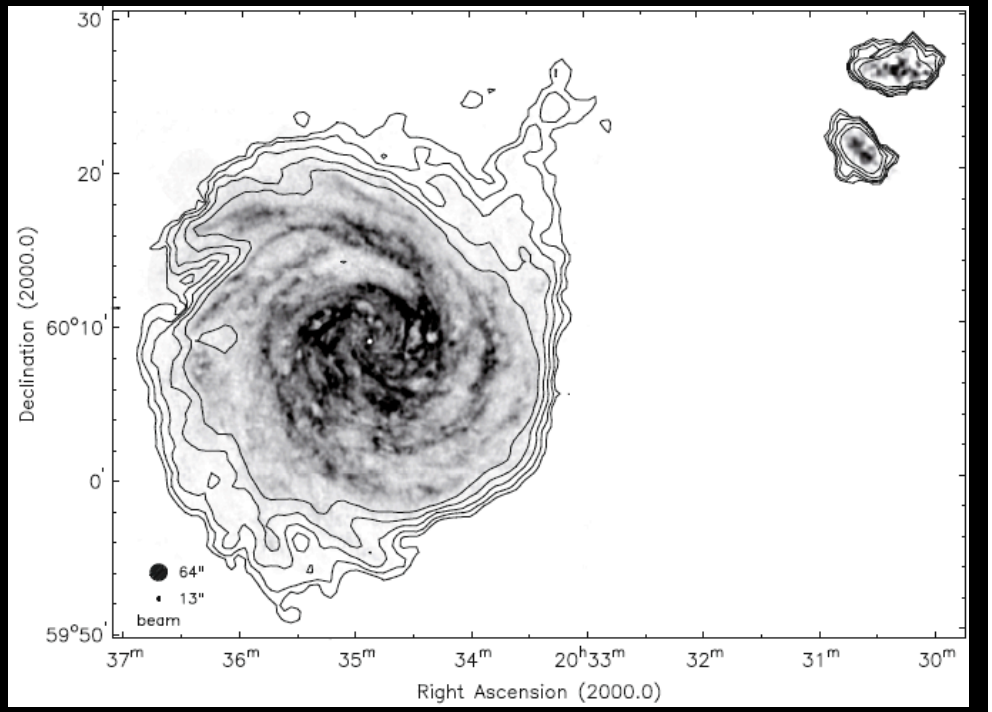

THINGS
The HI Nearby Galaxy Survey
The rest of this talk will mostly focus on the preliminary results from NGC 6946 and NGC 925
Walter et al. 2008
10 kpc

NGC 6946

(D ~ 6 Mpc)



THINGS data: Greyscale ranges from $N_{HI} \sim 10^{20\text{-}21.6}$ cm^{-2}



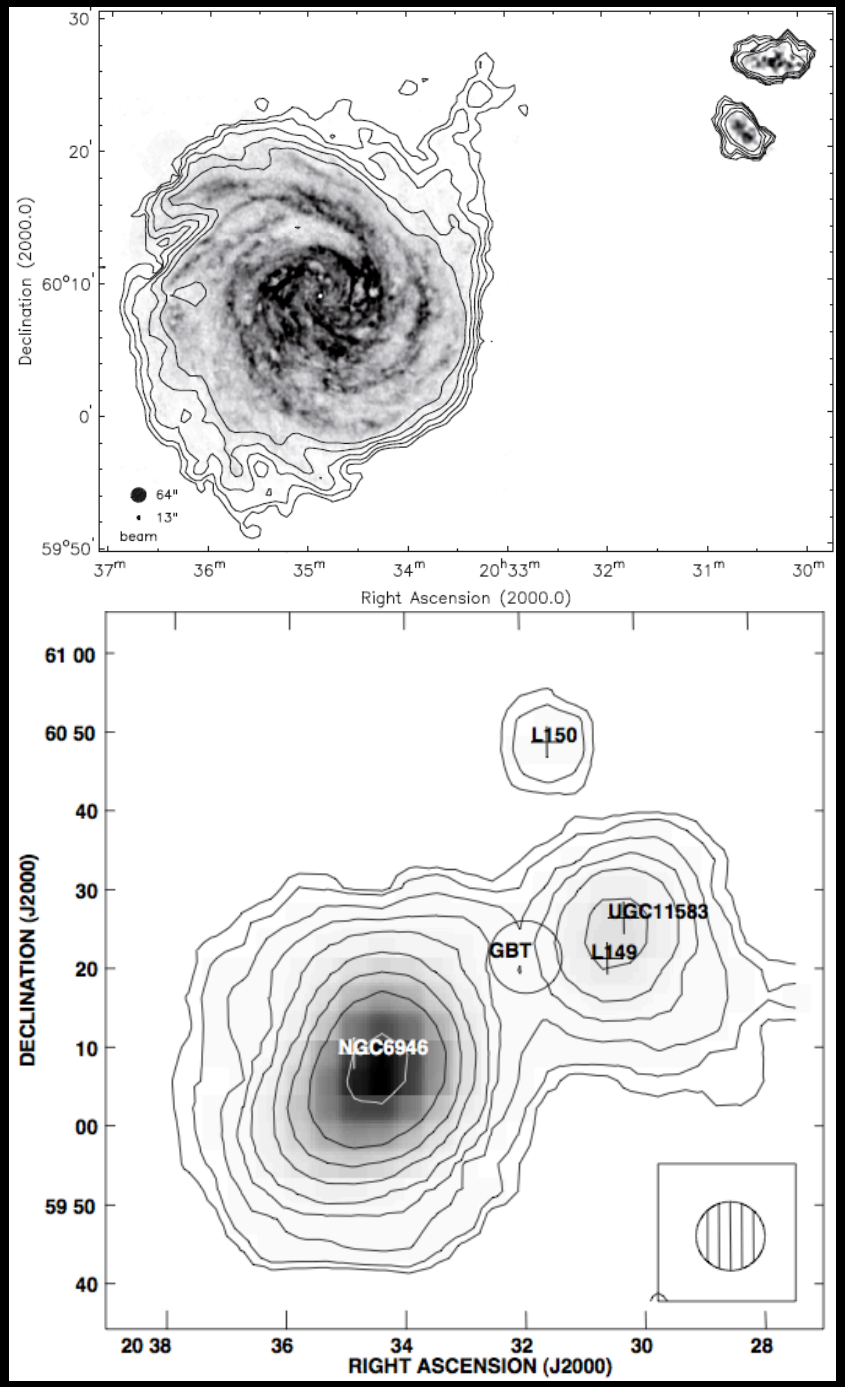
Boomsma et al. 2008, 192 hour WSRT map

lowest contour = 1.25×10^{19} cm^{-2}

Many HVCs seen associated with disk.

NGC 6946

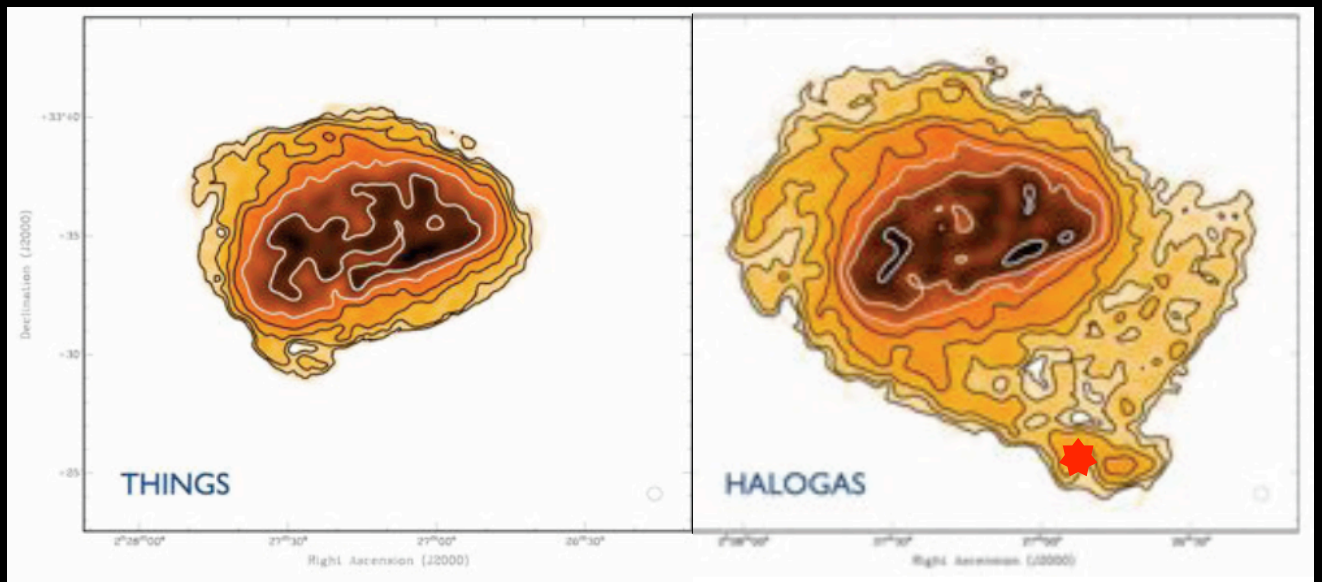
- GBT observations: contours at 0.7, 1.4, 3.5, 7, 14, 35, 70, 140x10^{18} cm^{-2}
- Filament has peak N_{HI} = 2x10^{18} cm^{-2} and FWHM = 48 km/s.
- The filament smoothly connects in position and velocity with NGC 6946 and companions.
- It is not consistent with stray-radiation, since any such features would be azimuthally-symmetric about NGC 6946.
- Filament could be a cold flow, but is more likely to be a tidal stream.



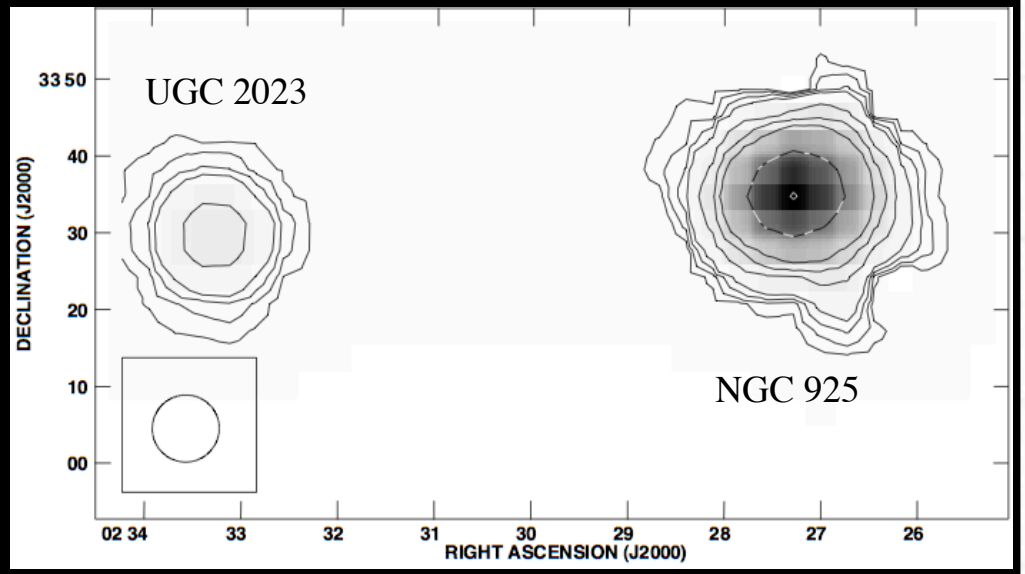
NGC 925

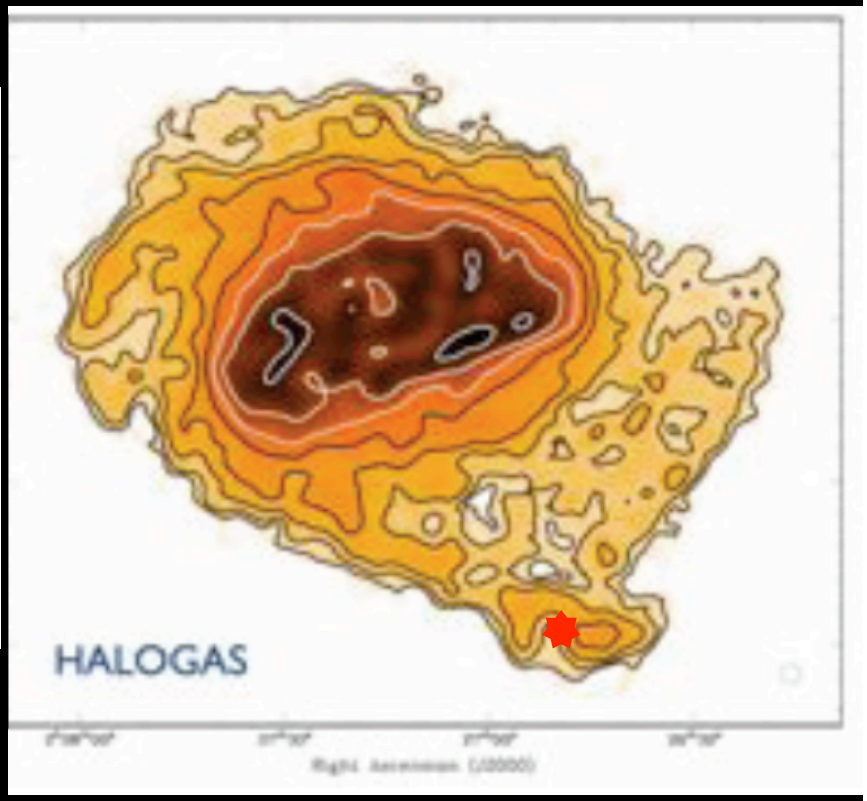
(D ~ 9.3 Mpc)

- THINGS data on left is relatively shallow and only shows a hint of asymmetry in NGC 925 HI distribution. Lowest contour at $N_{HI} = 9x10^{19}$ cm^{-2}.
- HALOGAS (Heald et al. 2011) observations confirm filament seen by Pisano et al. (1998) and show extensive extended HI around galaxy. Clump at end of filament has stars. Lowest contour at $N_{HI} = 1.8x10^{19}$ cm^{-2}.



NGC 925

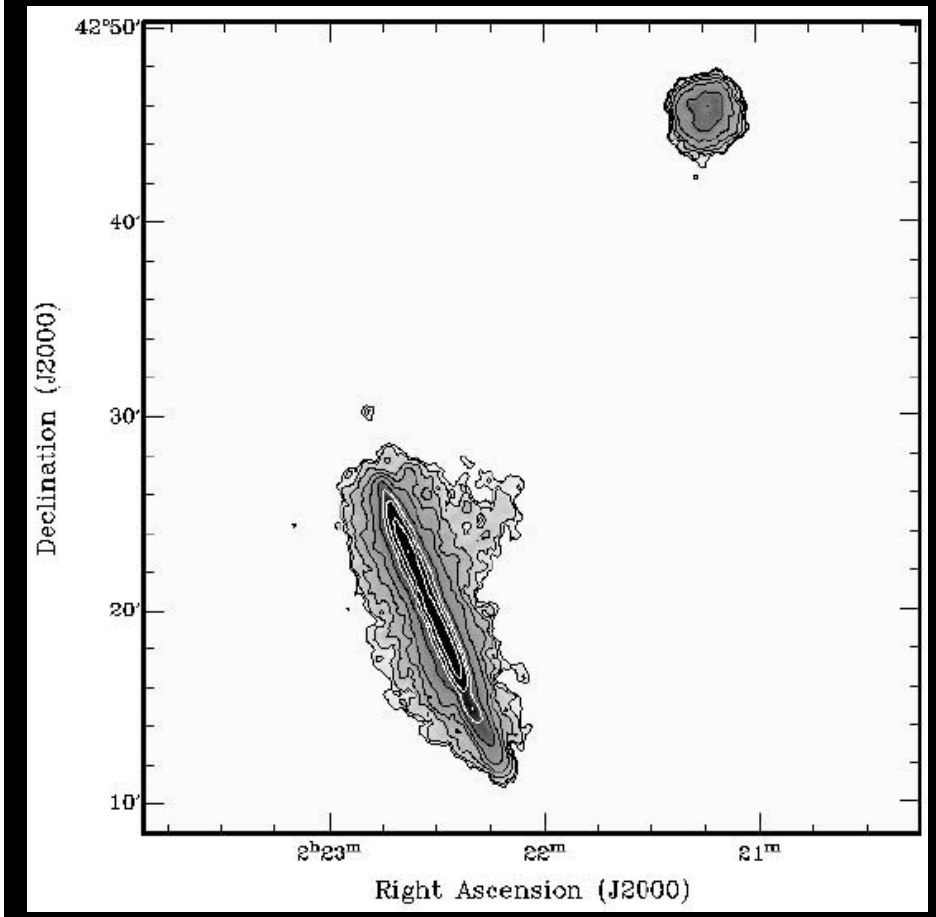


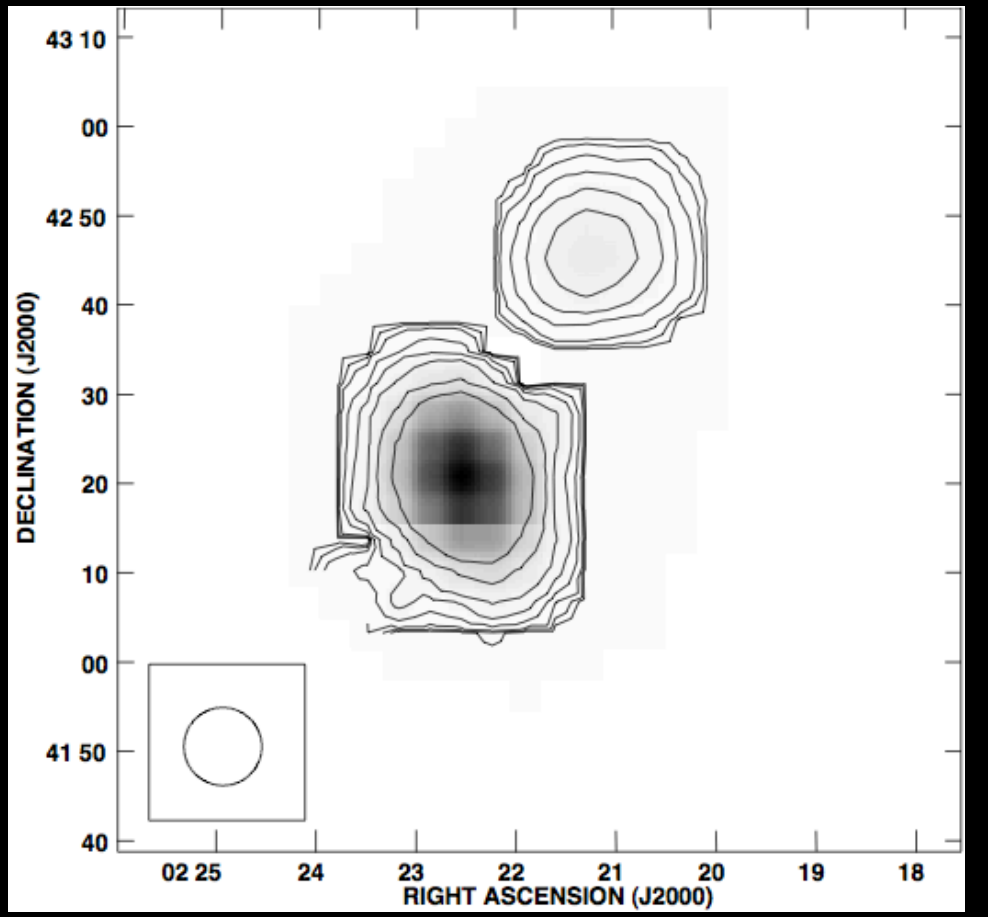


Preliminary reduction yields 3σ, 20 km/s sensitivity ~10^{18} cm^{-2}.
Can see the tidal features near NGC 925, but no connection with companion.
Absence of low N_{HI} features probably real, but may be due to distance of source.

Contours at 1, 3, 6, 10...600x10^{18} cm^{-2}.
See signs of extended HI around NGC 925, but no filamentary structures.

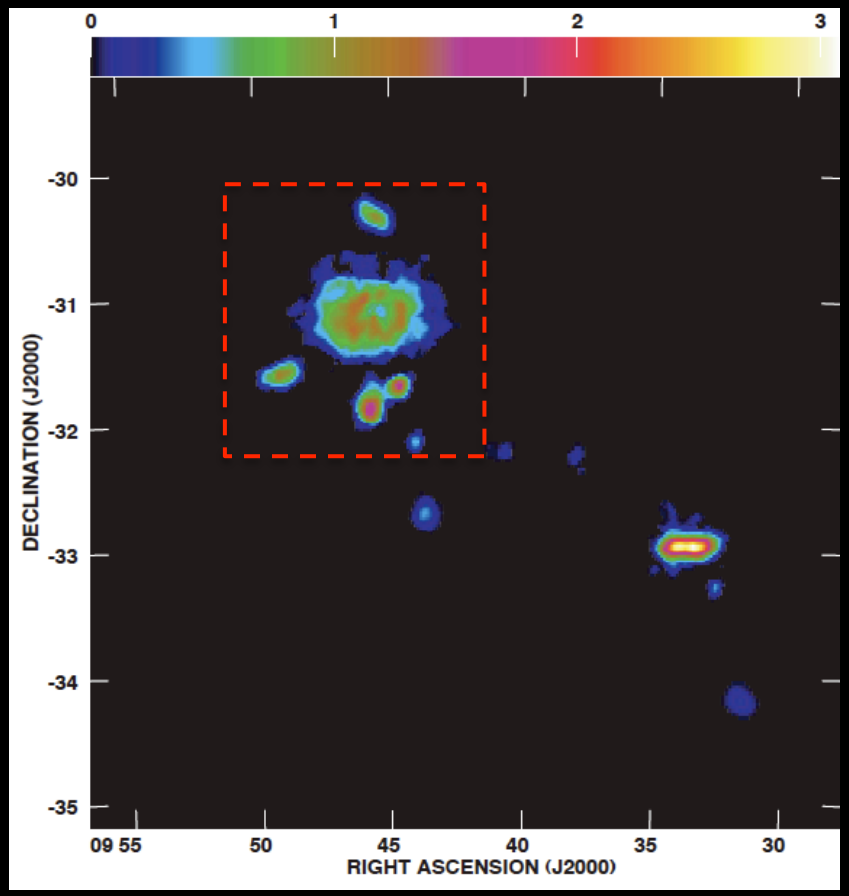
NGC 891

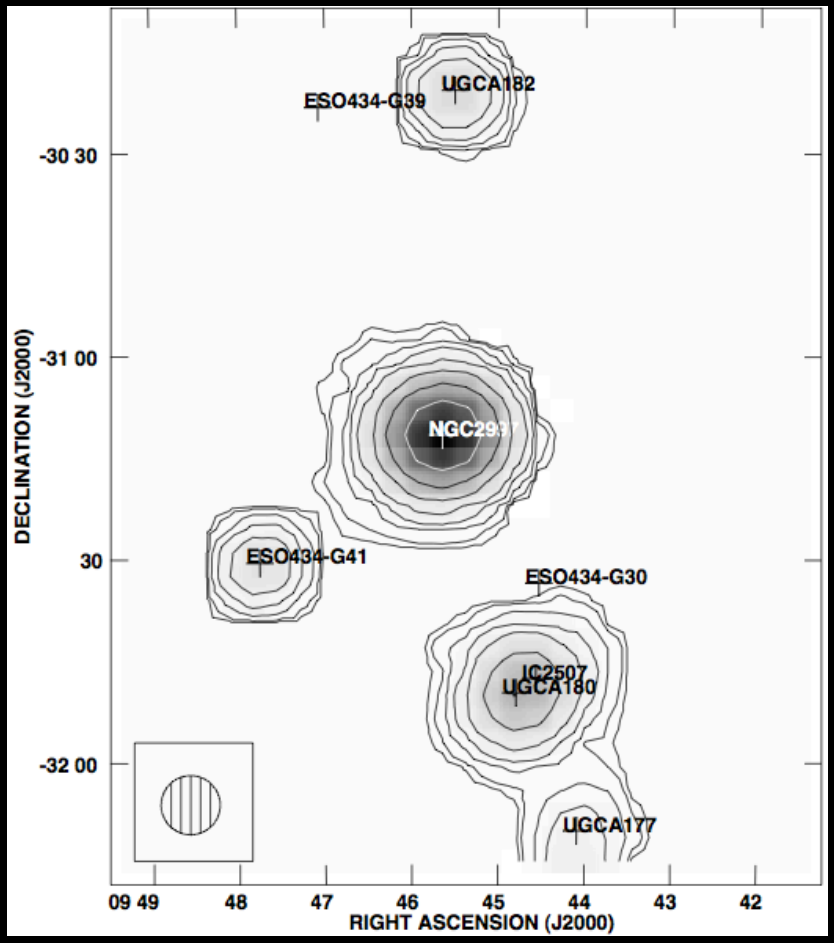




No signature of a filament connected NGC 891 to its companion at the $N_{HI} = 5x10^{17}$ cm^{-2} level in initial reduction.

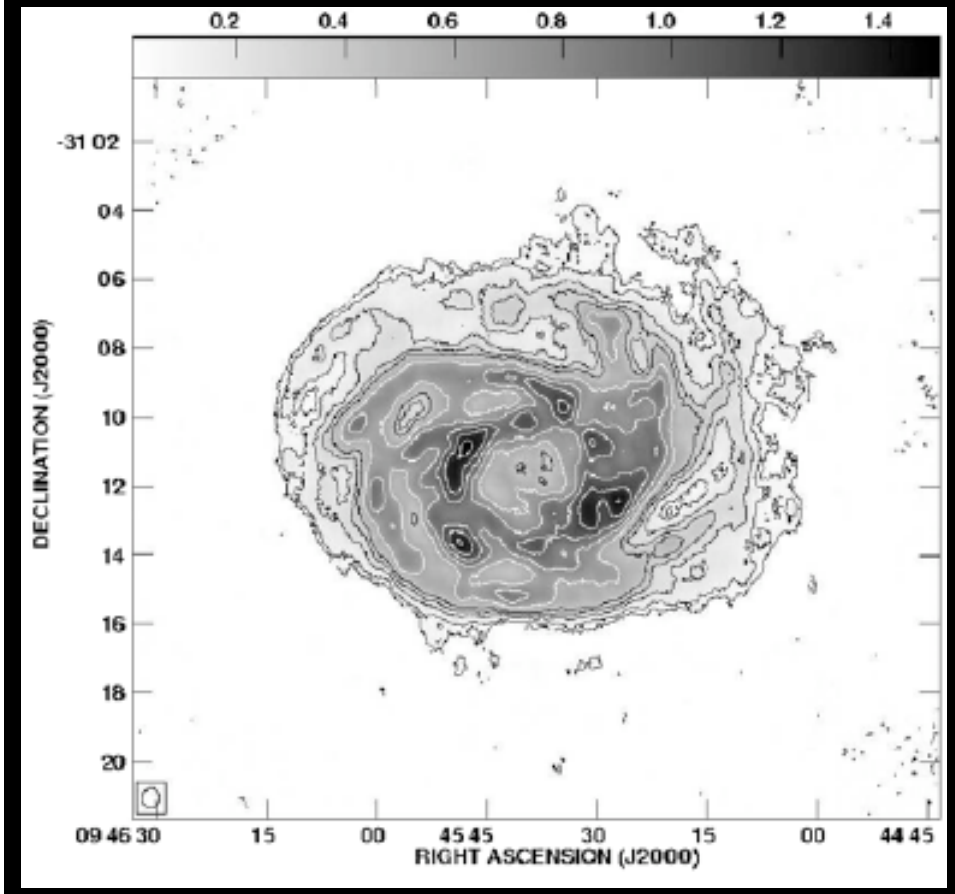
NGC 2997

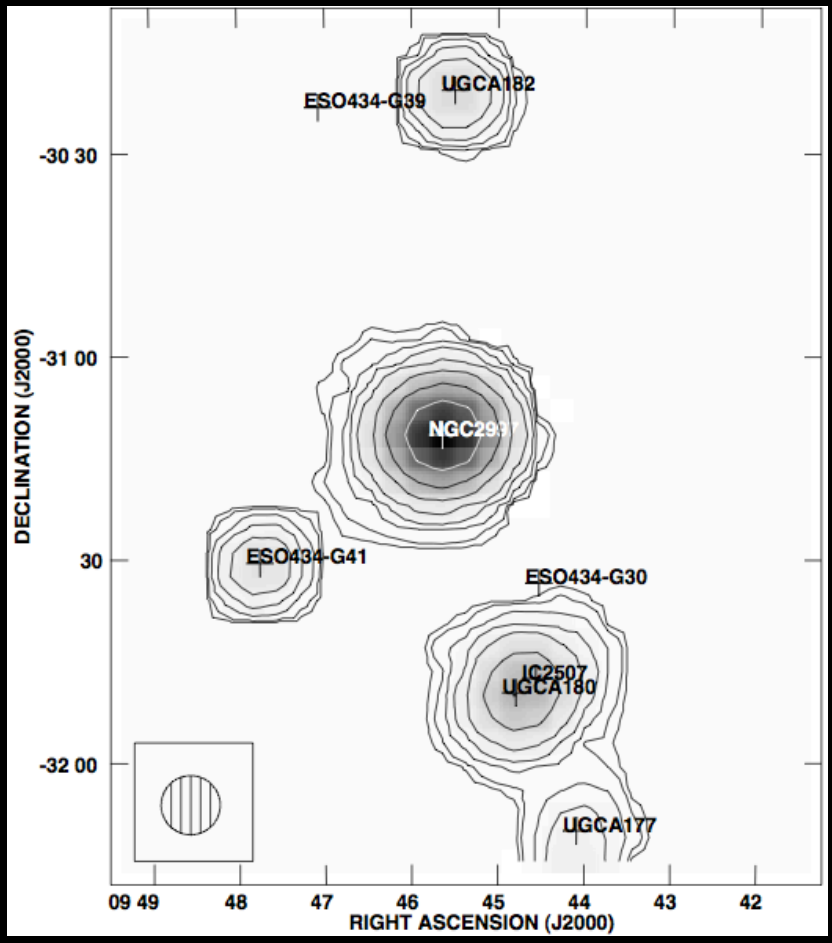




No discrete features at the $N_{HI} = 5x10^{17}$ cm^{-2} level.

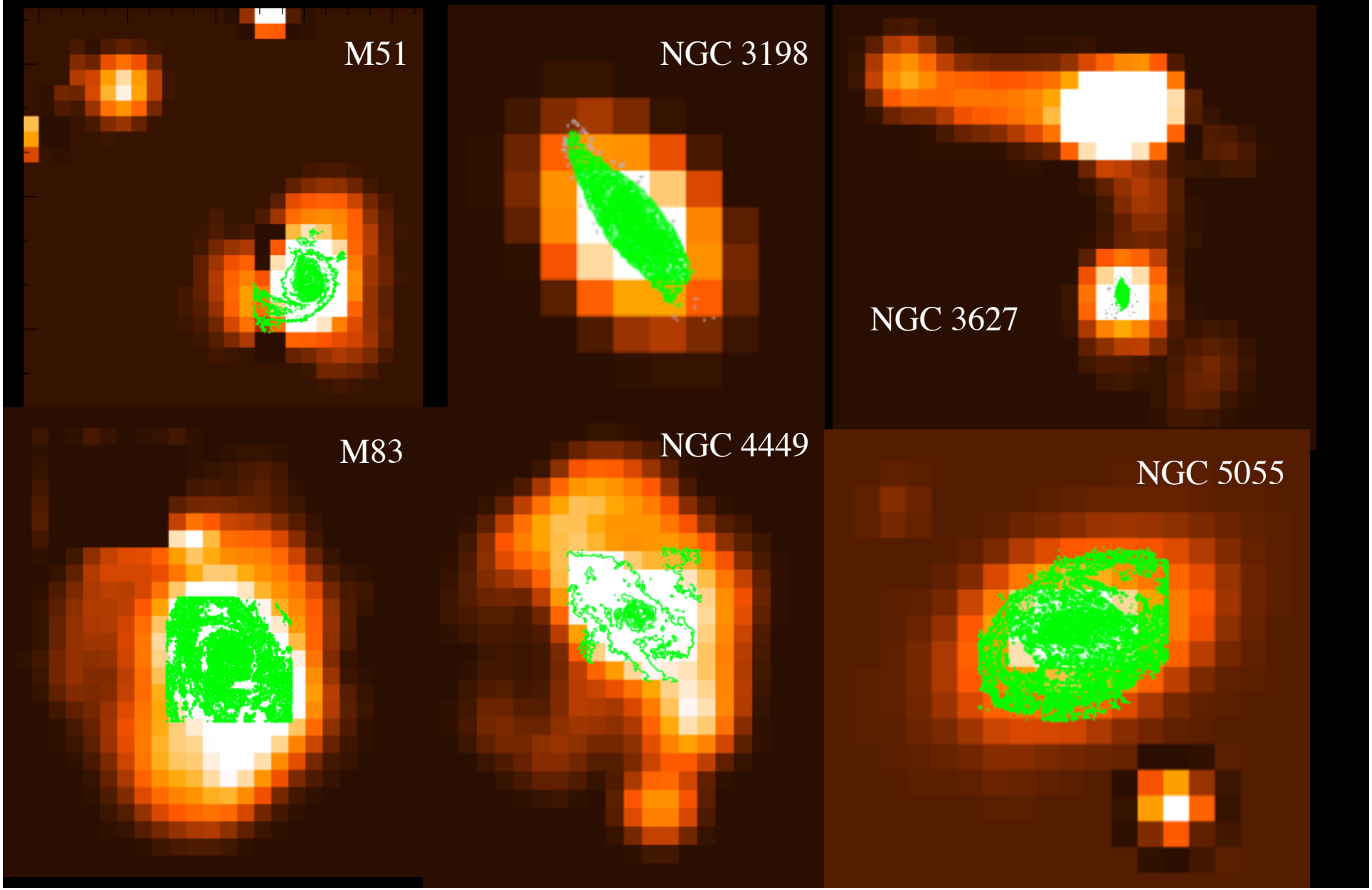
NGC 2997





No discrete features at the $N_{HI} = 5 \times 10^{17}$ cm^{-2} level, but HI is more extended at all column densities.

Preliminary Results for other THINGS galaxies



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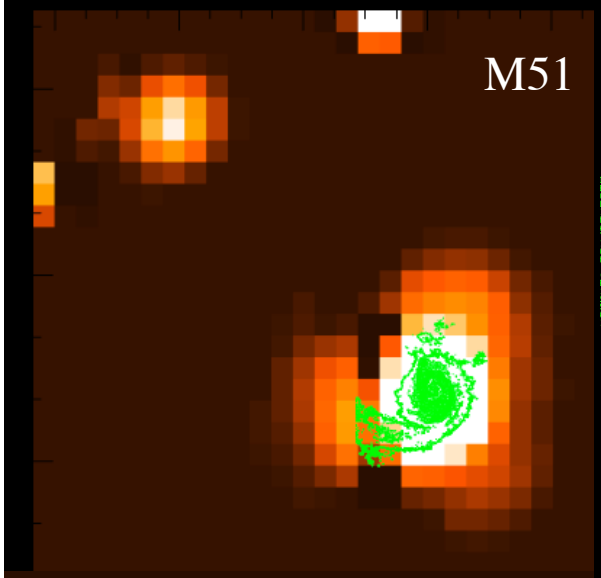

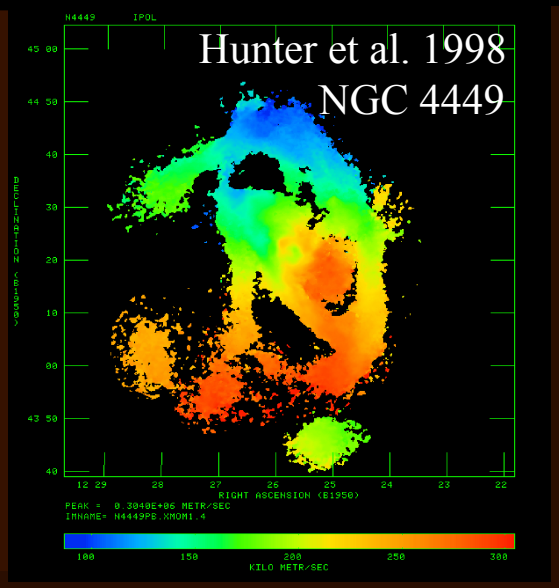

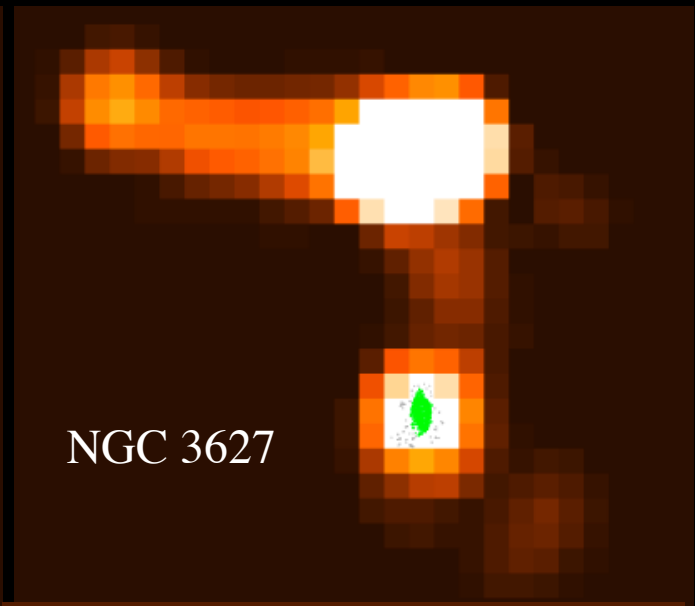

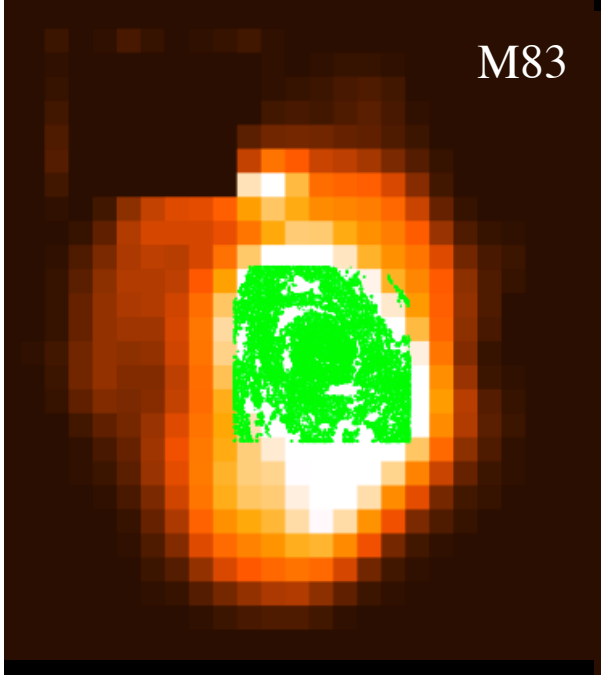

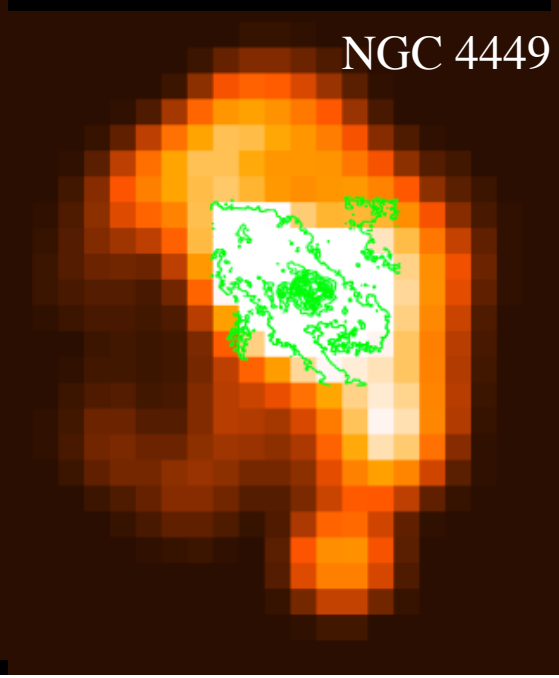

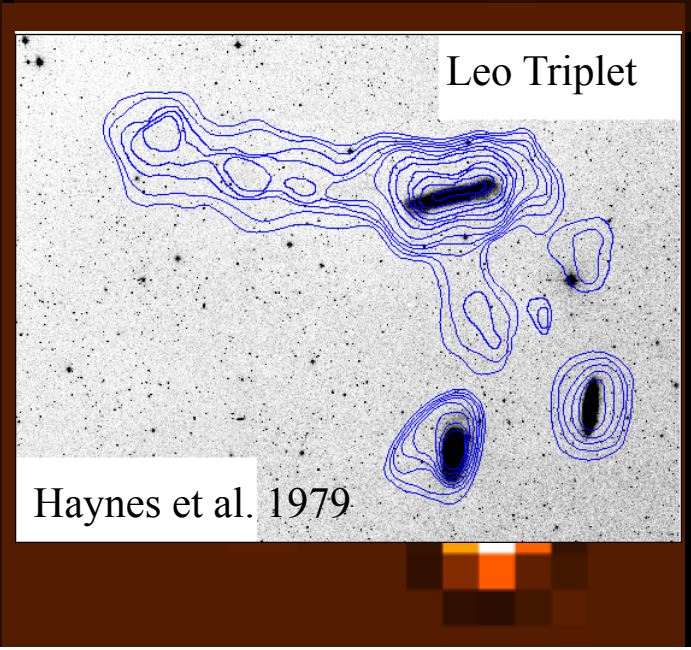

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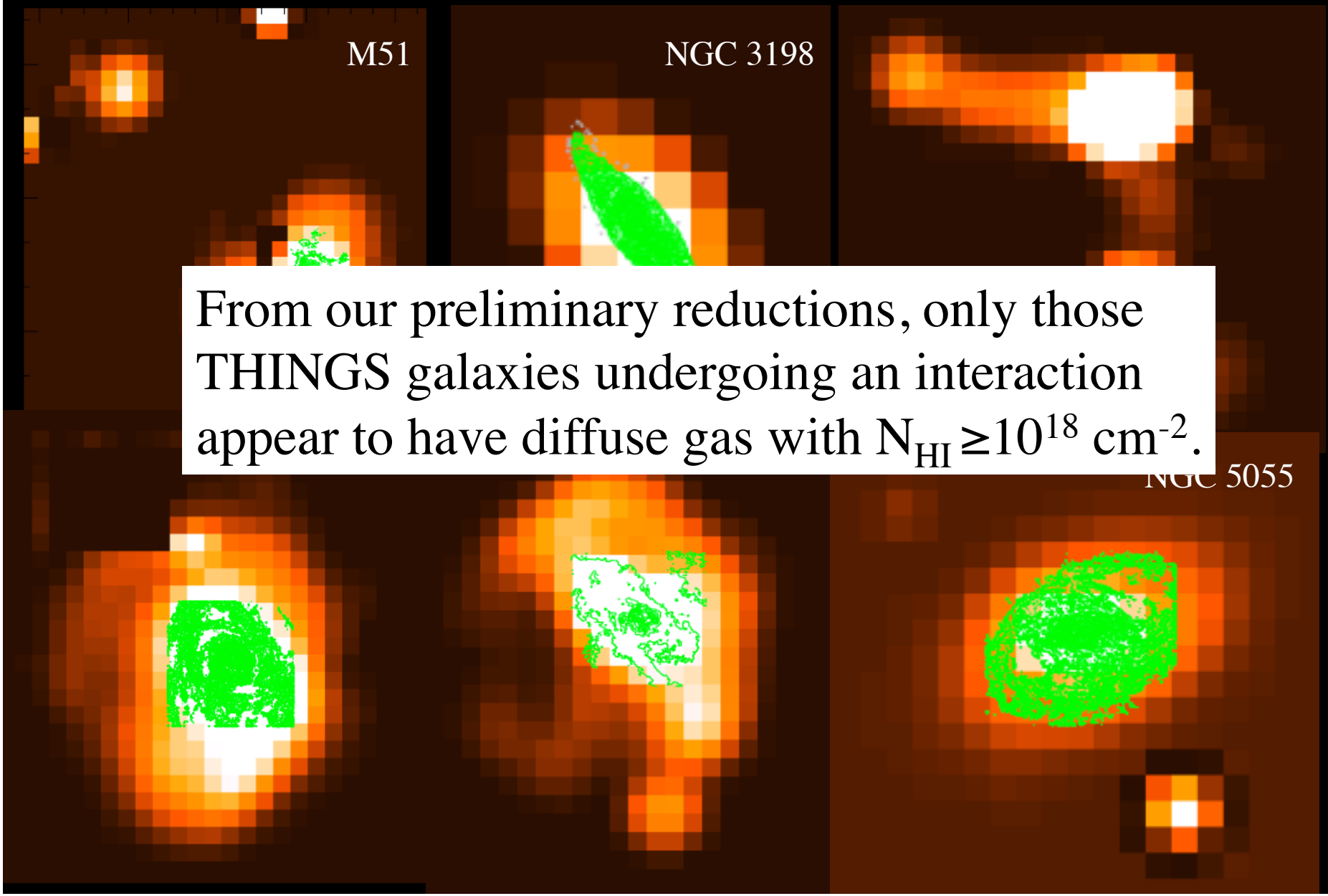

From our preliminary reductions, only those THINGS galaxies undergoing an interaction appear to have diffuse gas with $N_{HI} \geq 10^{18}$ cm^{-2}.

Conclusions

- We have mapped low column density HI emission around 21 THINGS galaxies with the GBT to provide total power data for studies of HI in galaxies and identify tidal features and cold flows around galaxies.
- NGC 6946 has filament with peak $N_{HI} = 2x10^{18}$ cm^{-2} connecting galaxy with nearby companions that is unseen by existing WSRT data. This is probably a tidal filament.
- NGC 925 has extended HI distribution, but no sign of any filaments. This could be due to beam dilution or real.
- NGC 925 is below the nominal transition halo mass, while NGC 6946 is close to it. NGC 6946 HI filament is consistent with being a tidal feature.

Future Work

- A preliminary analysis of the rest of the THINGS galaxies suggests that surrounding diffuse HI is only present when a tidal interaction has occurred. To identify cold flows, need to observe galaxies spanning a wide range of masses, SFR, and environment.
- We plan to observe the 24 galaxy HALOGAS sample.
- MHONGOOSE survey with MeerKAT will provide 6000 hours of HI data for 30 galaxies. GBT will help provide single-dish data for these galaxies.
- Conducting detailed GBT study of M31-M33 HI bridge (see talk/poster by Lockman & Wolfe).