Mapping HI below $N_{HI} \sim 10^{18}\ cm^{-2}$

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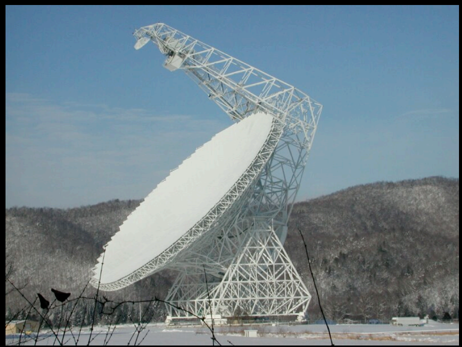
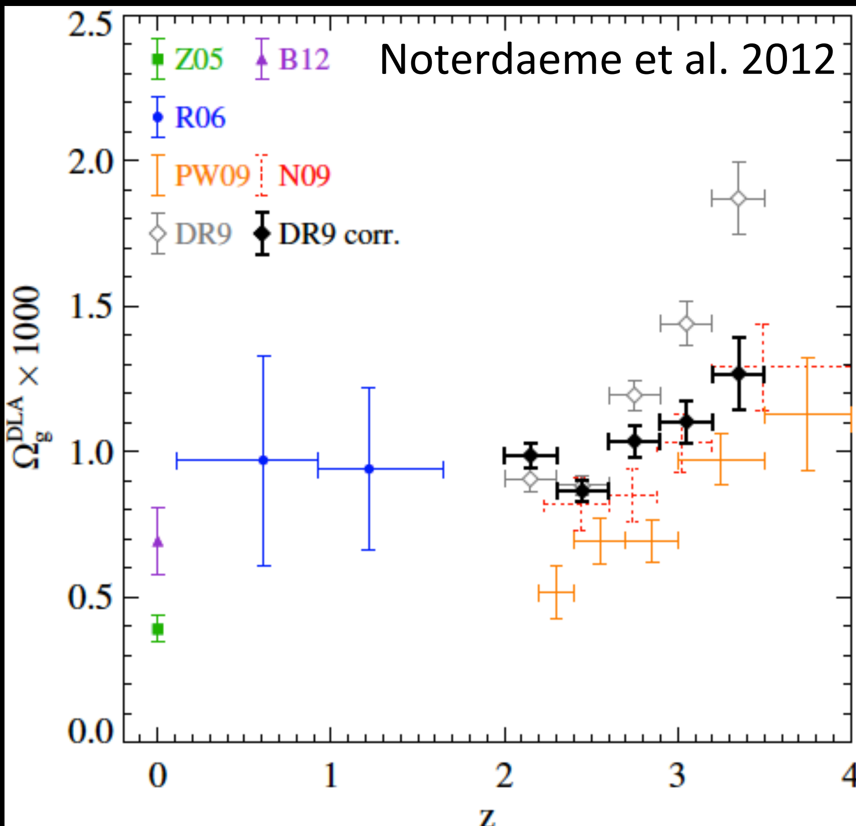
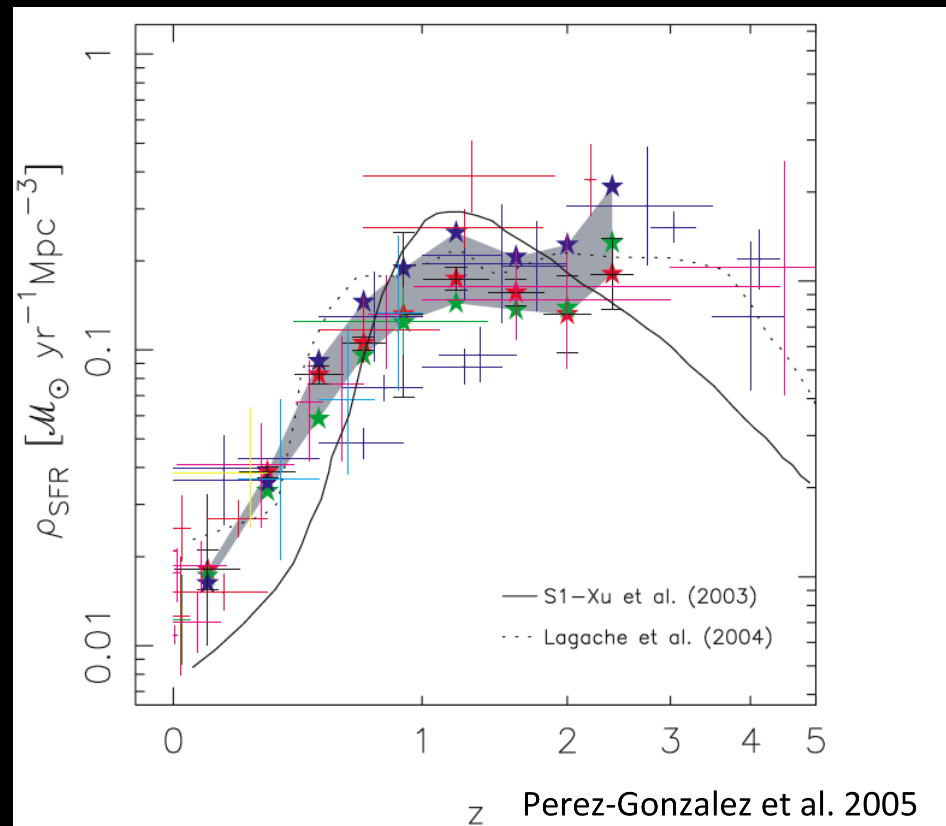


Comparing the evolution of HI content and SFR

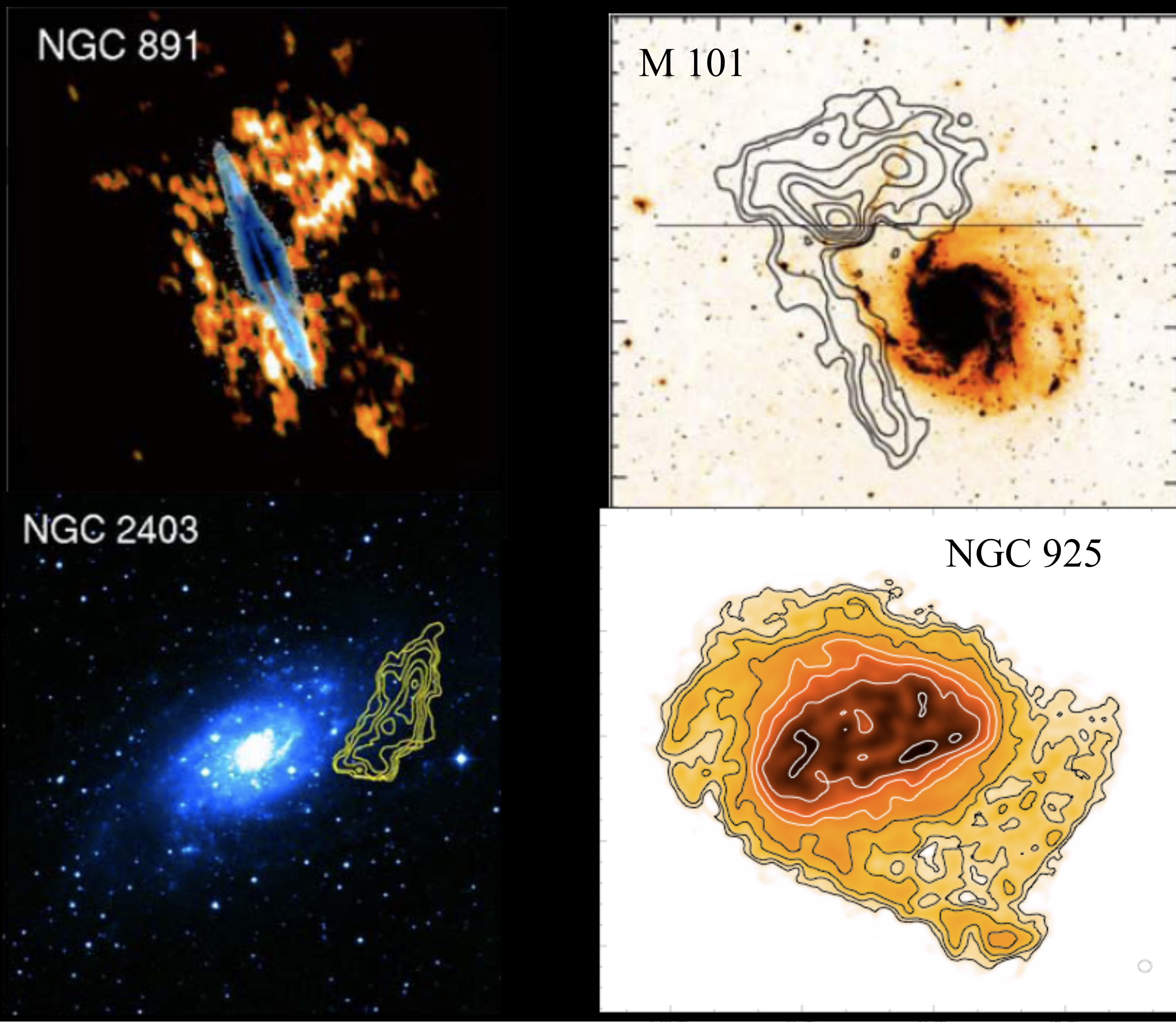




While the HI content of galaxies has remained relatively constant since z ~ 2-5, the SFR was 10x higher at z ~ 1.

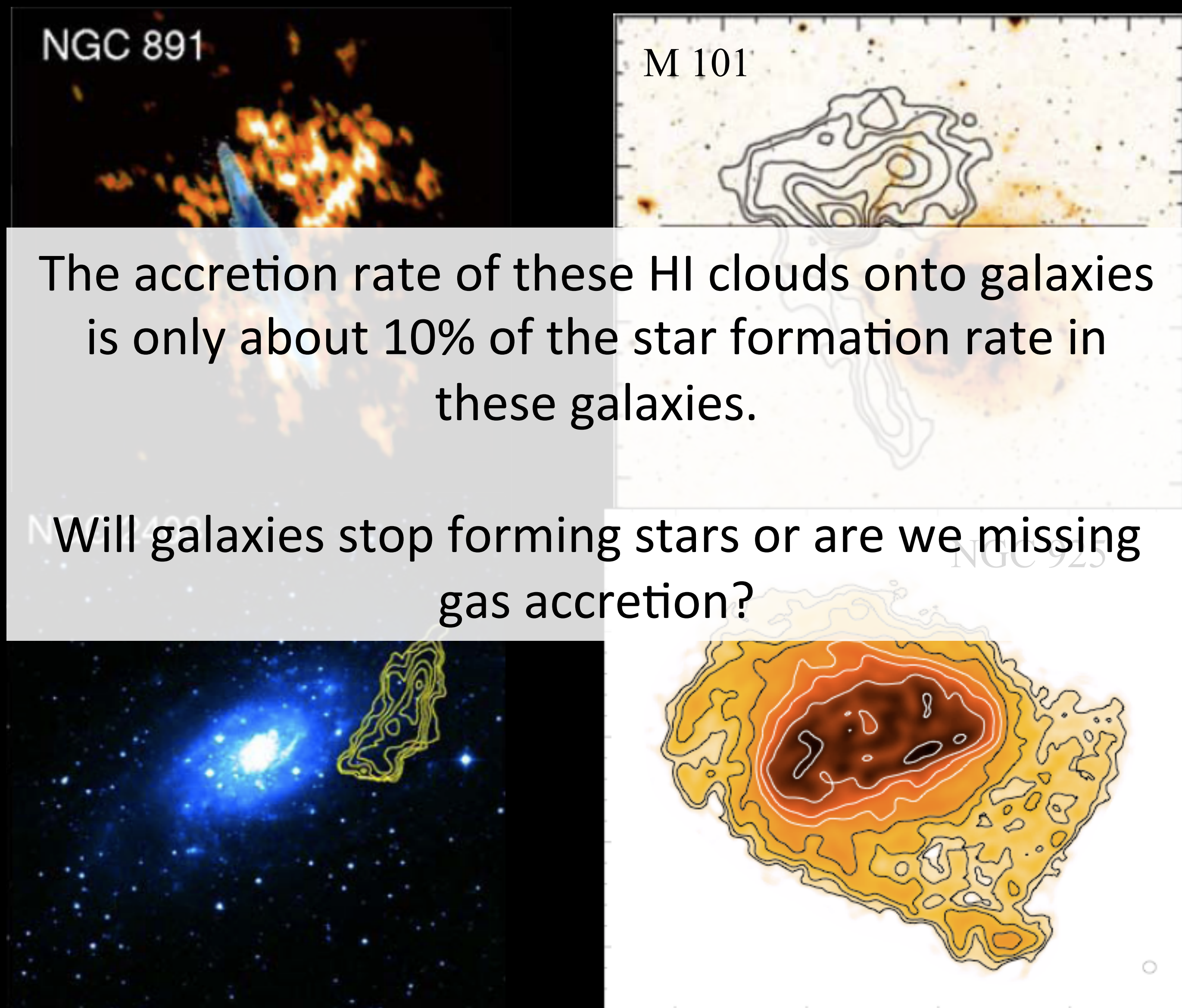
Galaxies must have accreted gas from the IGM.

Ongoing accretion of gas onto nearby galaxies?



Sancisi et al.
2008

Ongoing accretion of gas onto nearby galaxies?



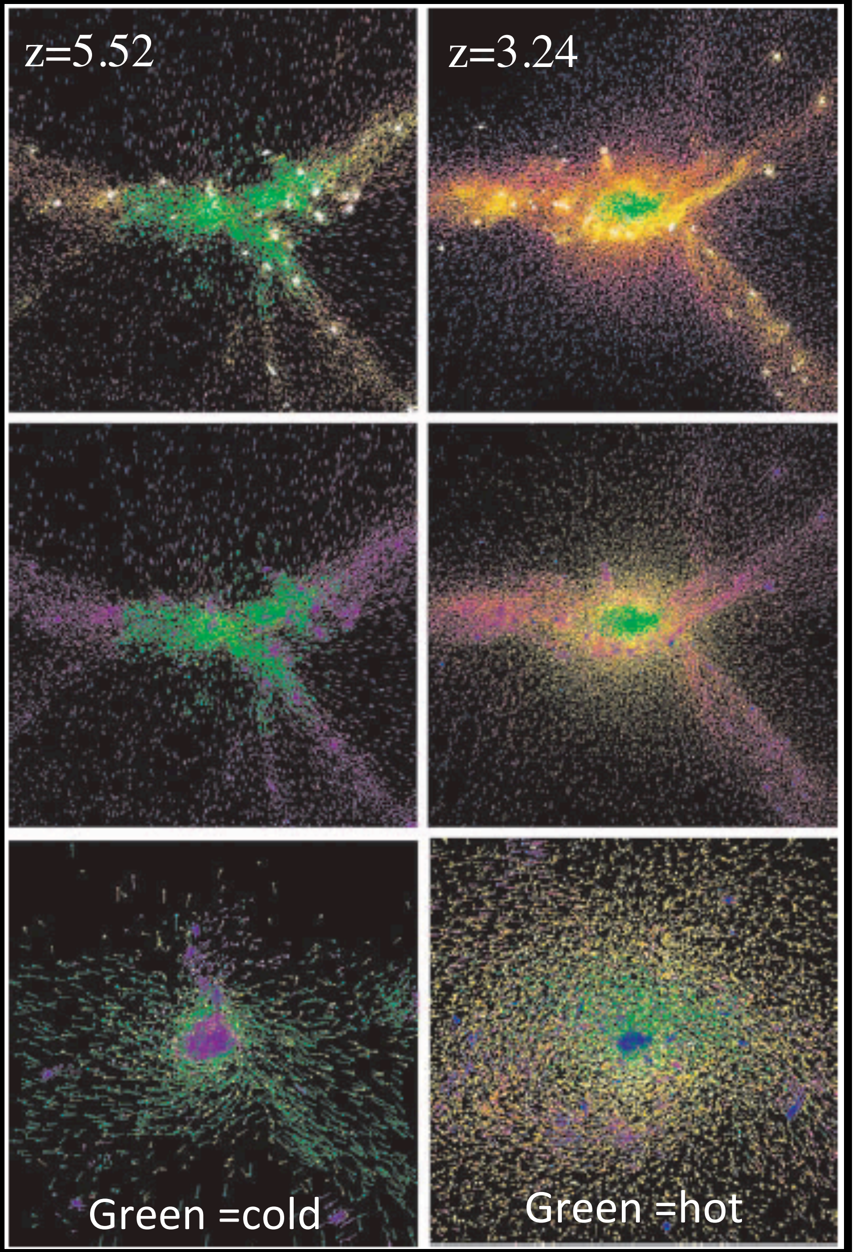
The accretion rate of these HI clouds onto galaxies is only about 10% of the star formation rate in these galaxies.

Will galaxies stop forming stars or are we missing gas accretion?

Sancisi et al. 2008

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 and is accreted quasi-spherically.
- 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.

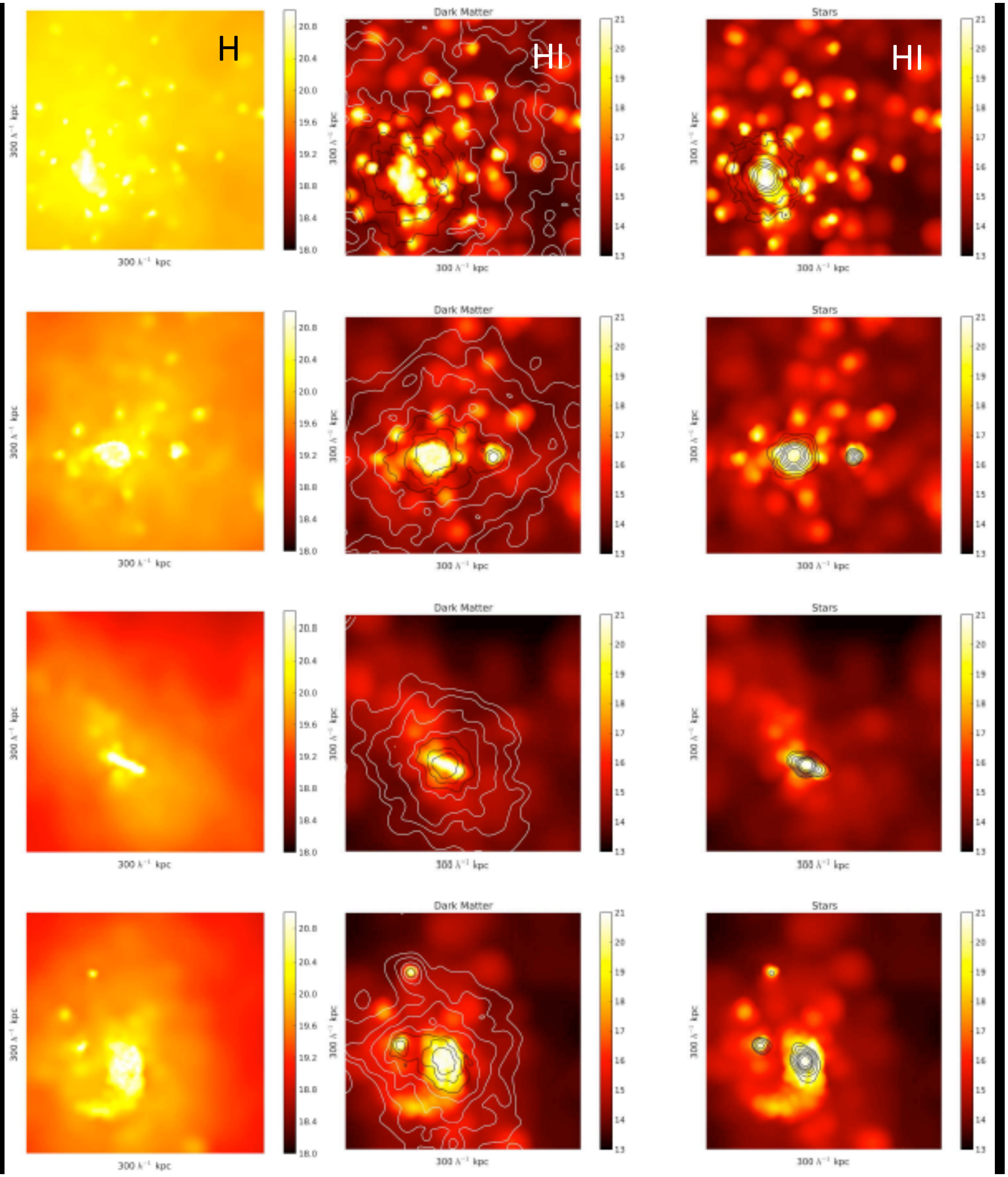


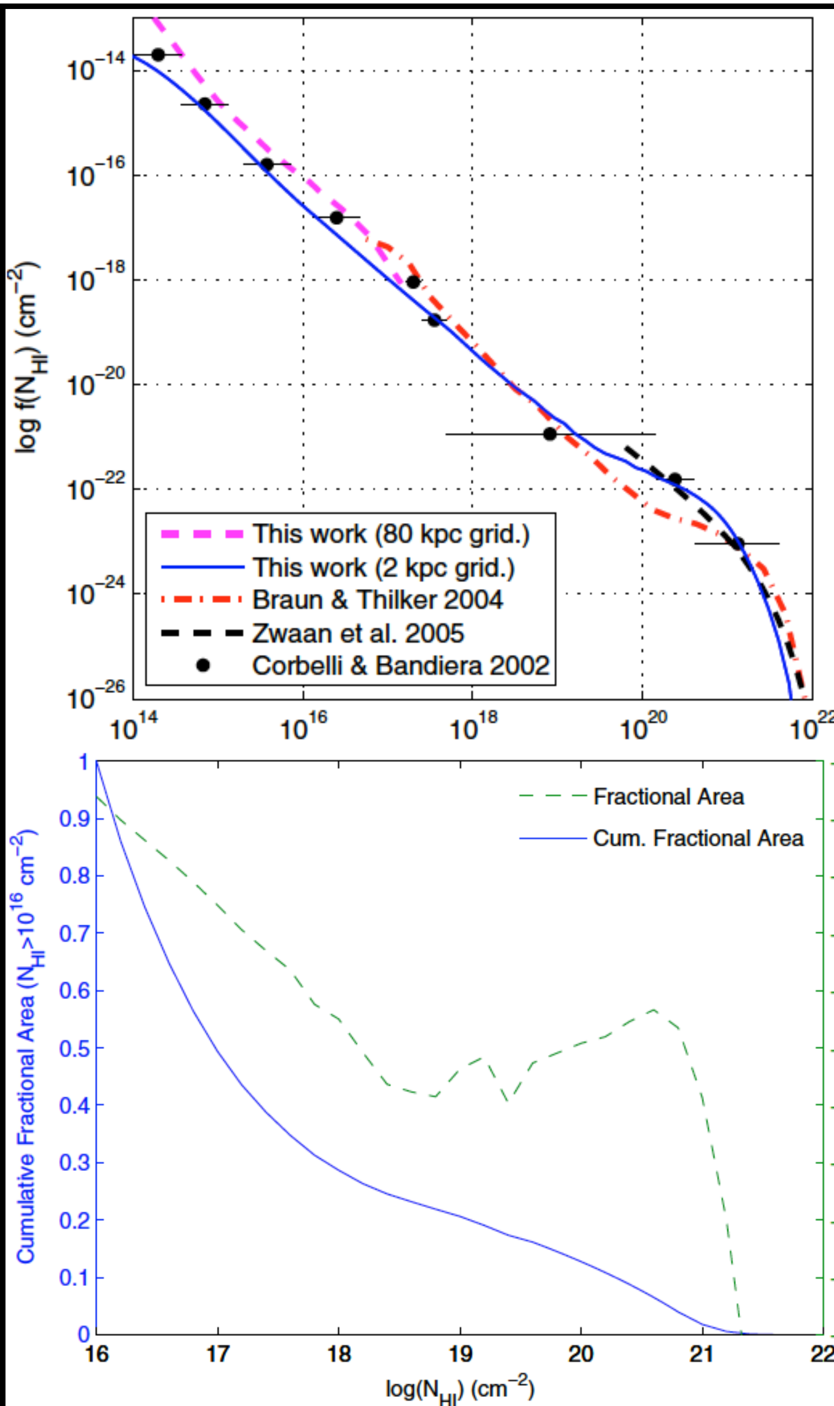
Keres et al. 2005

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





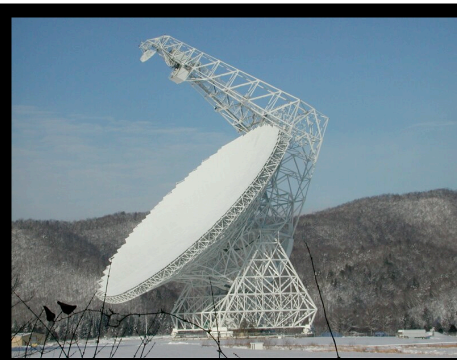
HI distributions

- From simulations (Popping et al. 2009) matched to Lyman α absorption lines and 21 cm emission statistics. Whatever its origin, we expect:
- ~16% of sightlines to have $N_{HI} > 10^{19}$ cm^{-2}
- ~26% of sightlines to have $N_{HI} > 10^{18}$ cm^{-2}
- ~48% of sightlines to have $N_{HI} > 10^{17}$ cm^{-2}

What is the distribution of this HI?

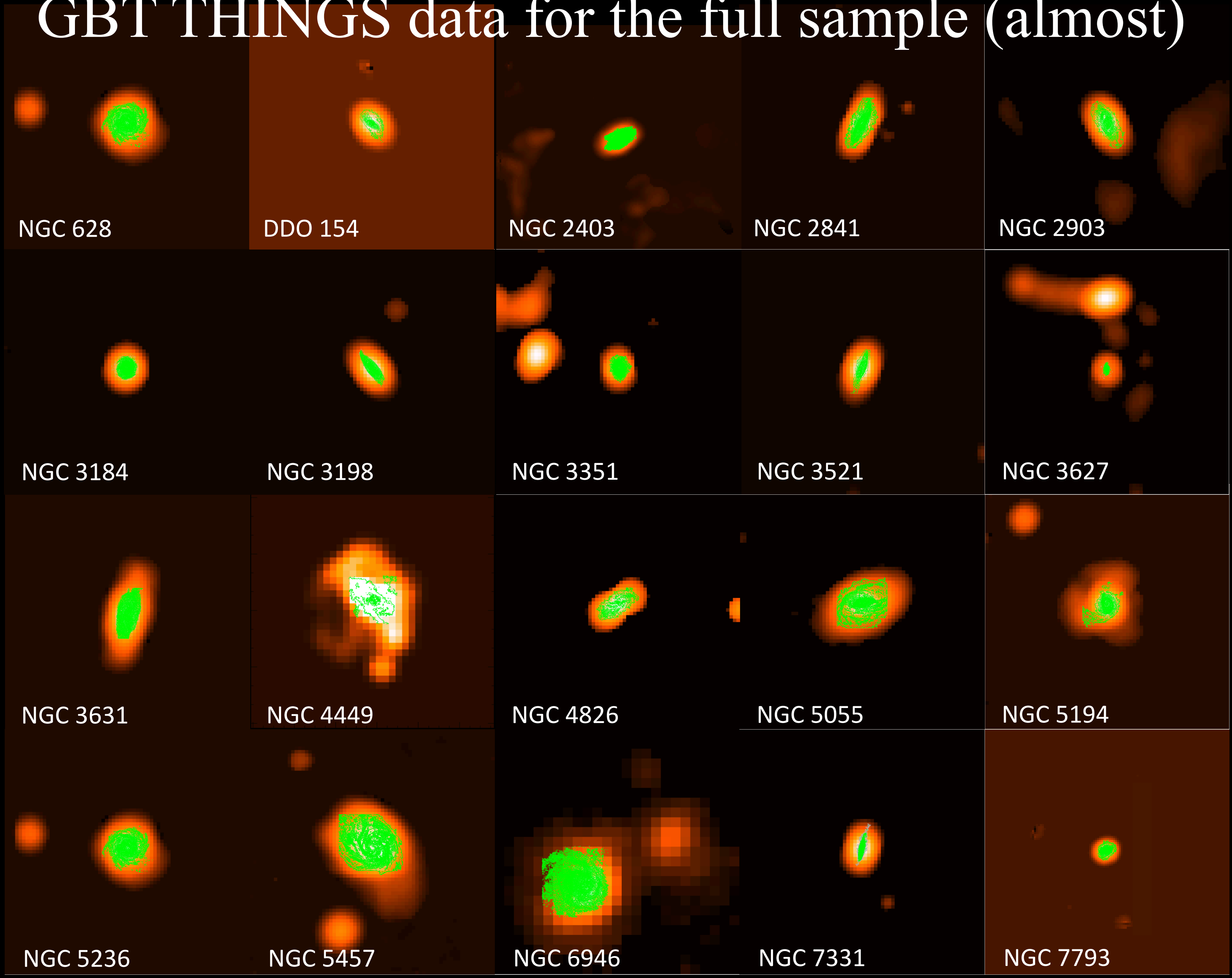
- Lyman α absorption lines give excellent measurements of the frequency of a given N_{HI} and its physical properties (e.g. metallicity), particularly at low N_{HI}.
- Most of the previous HI maps were made with *interferometers* (VLA, WSRT). These are very sensitive to clumpy HI clouds.
- To **map** faint, diffuse HI around individual galaxies, however, we need to use a *single-dish* radio telescope (like the GBT).

GBT Observations



- Green Bank Telescope (GBT) has unmatched combination of sensitivity and resolution *as well as very low sidelobes!*
- Have mapped 4 □° around ~40 galaxies at 9.2' resolution with a 3σ, 25 km/s detection limit of $N_{HI} \sim 1.3 \mathrm{x} 10^{18}$ cm^{-2}. (Stick around for talk by N. Pingel after coffee.)
- We have done a sparse grid of individual pointings around NGC 2403, NGC 3198, and M 31 with a 3σ, 25 km/s detection limit of $N_{HI} \sim 1\text{-}2 \mathrm{x} 10^{17}$ cm^{-2}.
- Have mapped 12 □° around M31 down to 3σ, 25 km/s detection limit of $N_{HI} \sim 1.6 \mathrm{x} 10^{17}$ cm^{-2}.

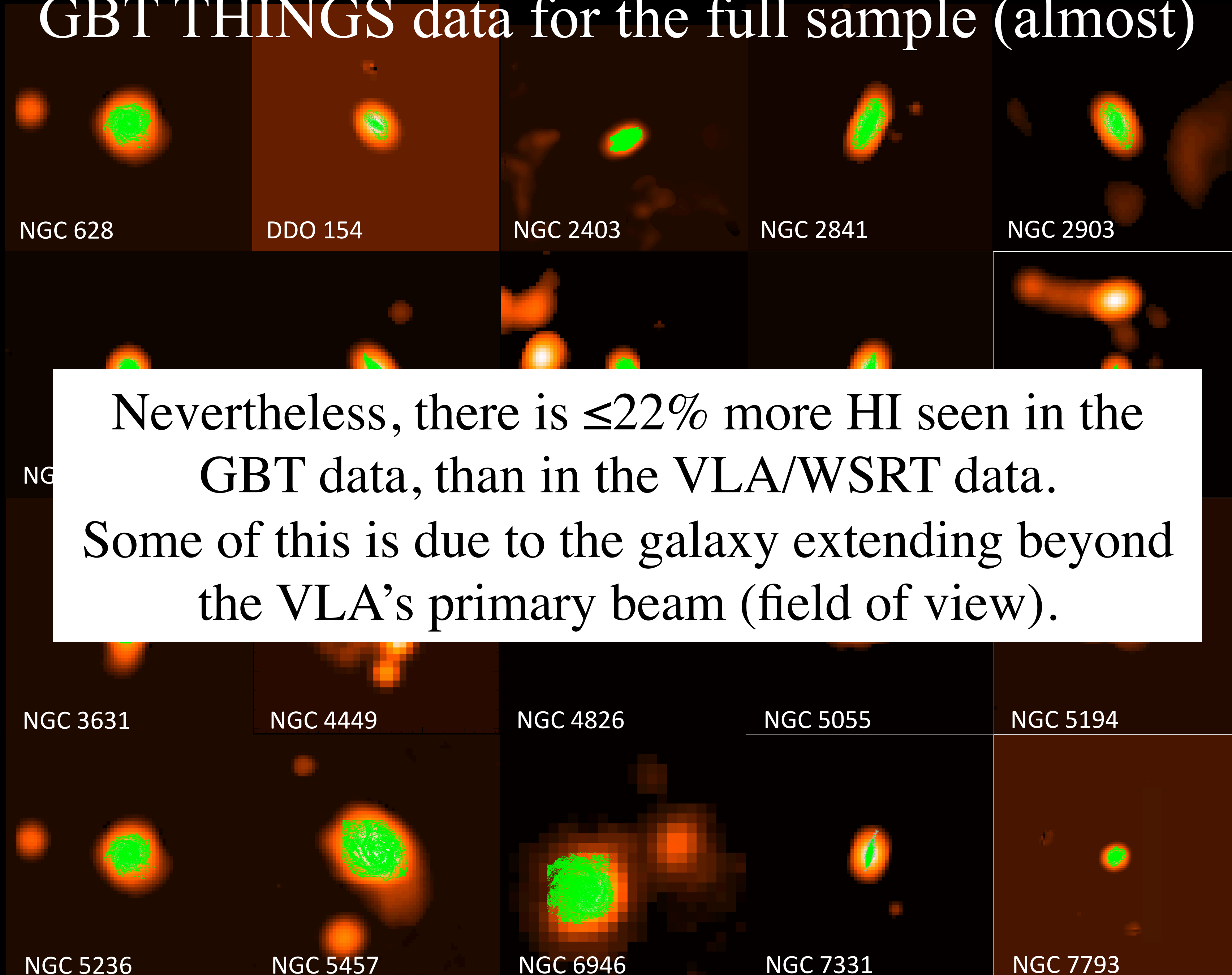
GBT THINGS data for the full sample (almost)



GBT THINGS data for the full sample (almost)

Based on a first look, only those THINGS galaxies undergoing an interaction appear to have diffuse gas features with $N_{HI} \geq 10^{18}$ cm^{-2}.

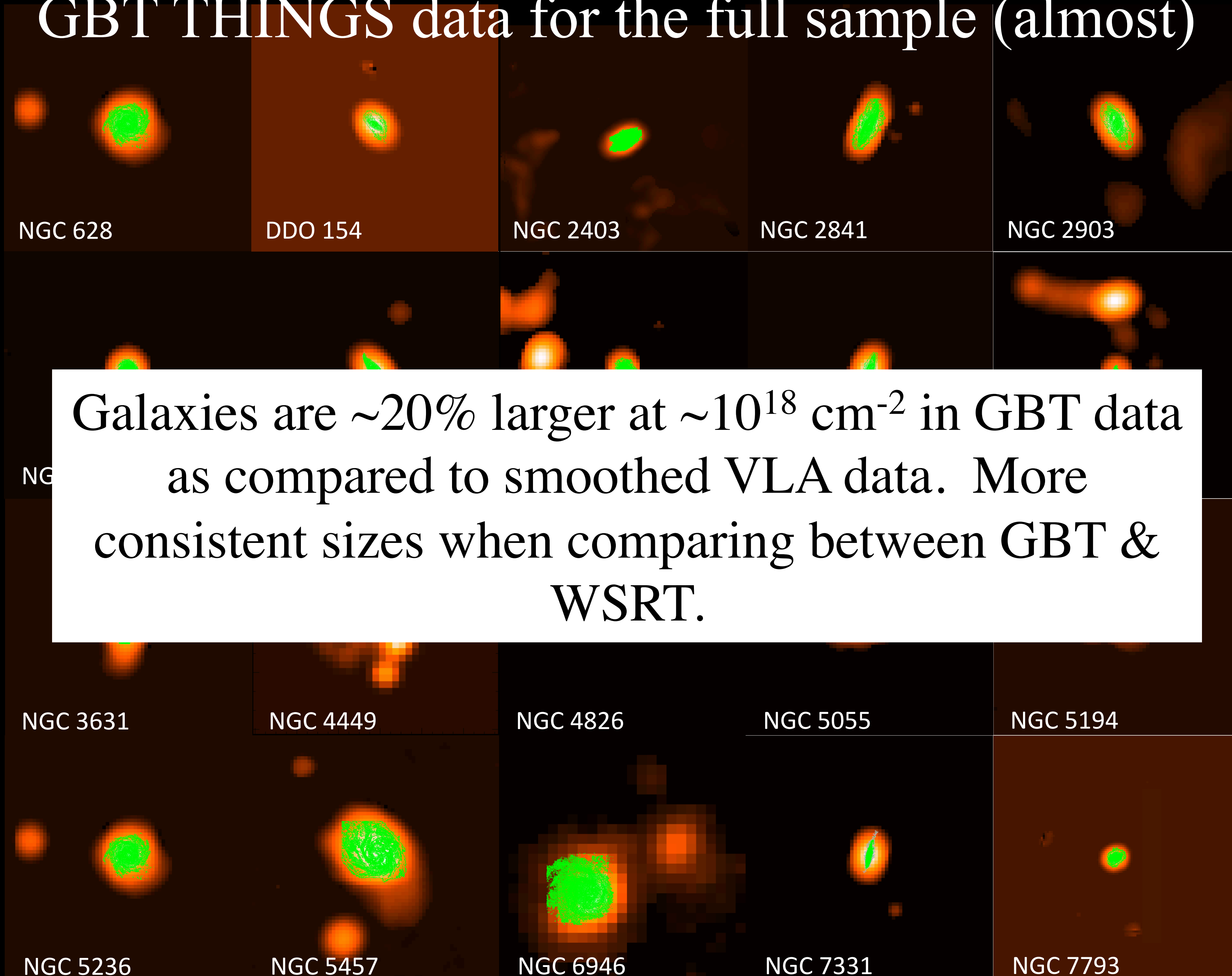
GBT THINGS data for the full sample (almost)



Nevertheless, there is ≤22% more HI seen in the GBT data, than in the VLA/WSRT data.

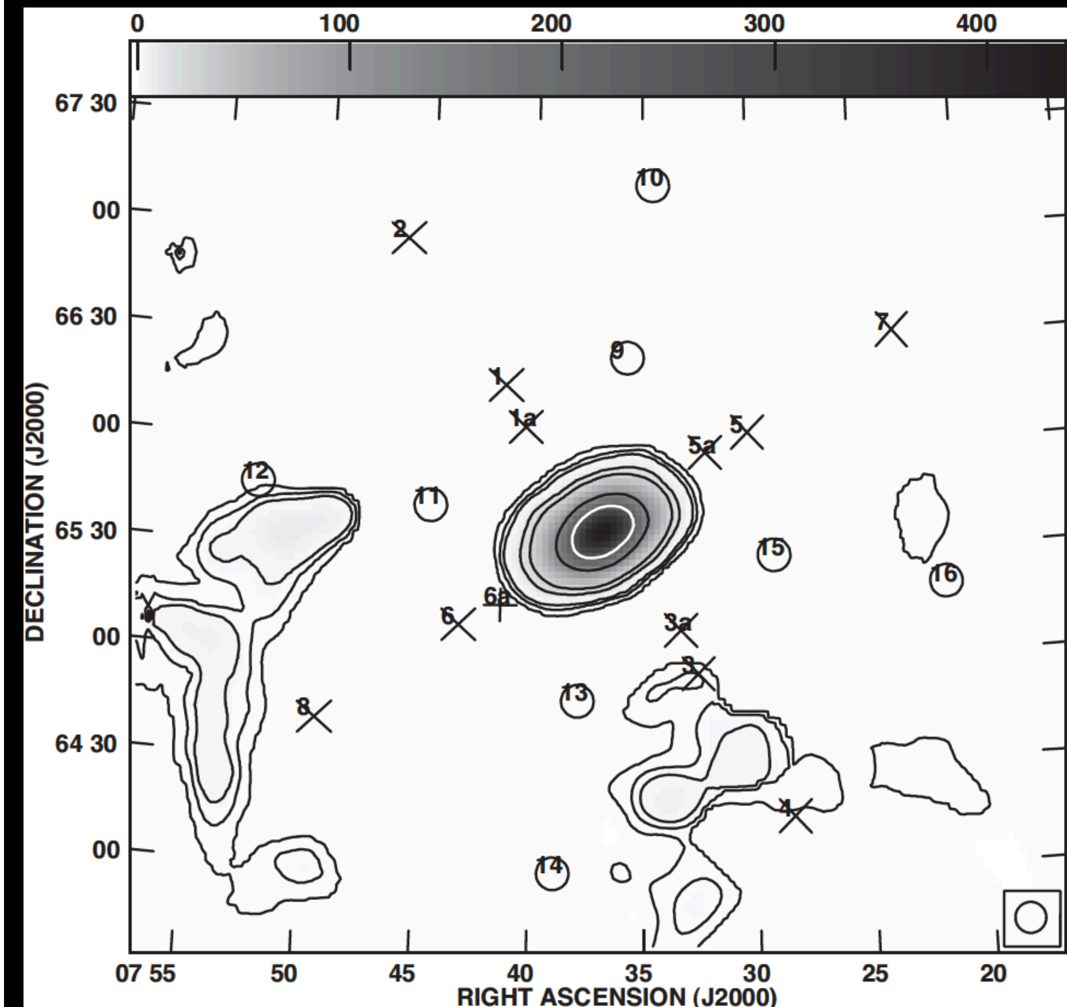
Some of this is due to the galaxy extending beyond the VLA's primary beam (field of view).

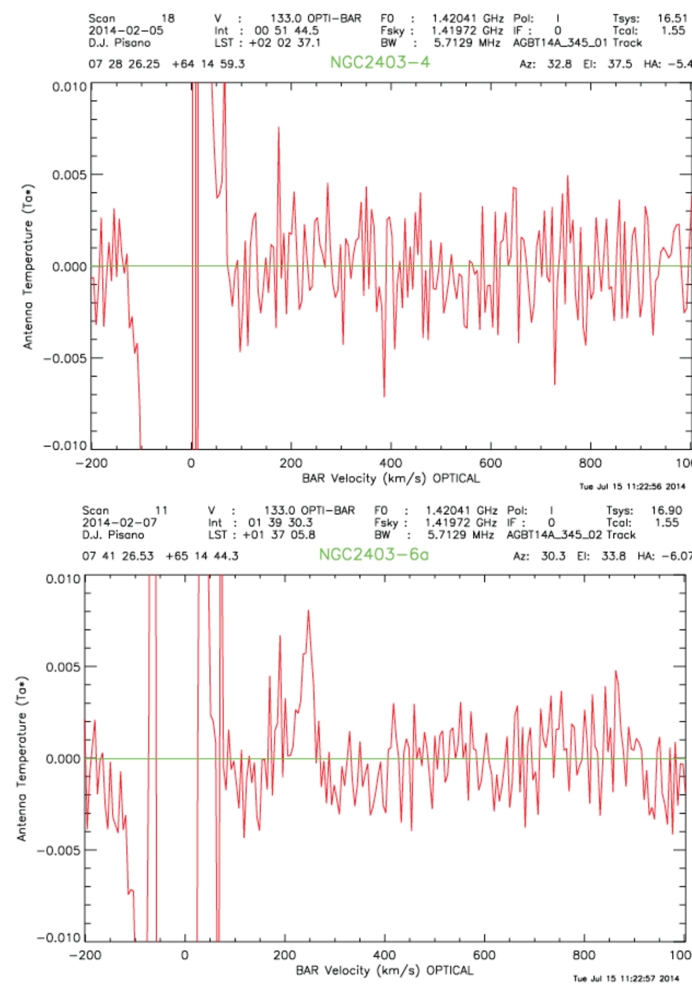
GBT THINGS data for the full sample (almost)



Galaxies are ~20% larger at ~10^{18} cm^{-2} in GBT data as compared to smoothed VLA data. More consistent sizes when comparing between GBT & WSRT.

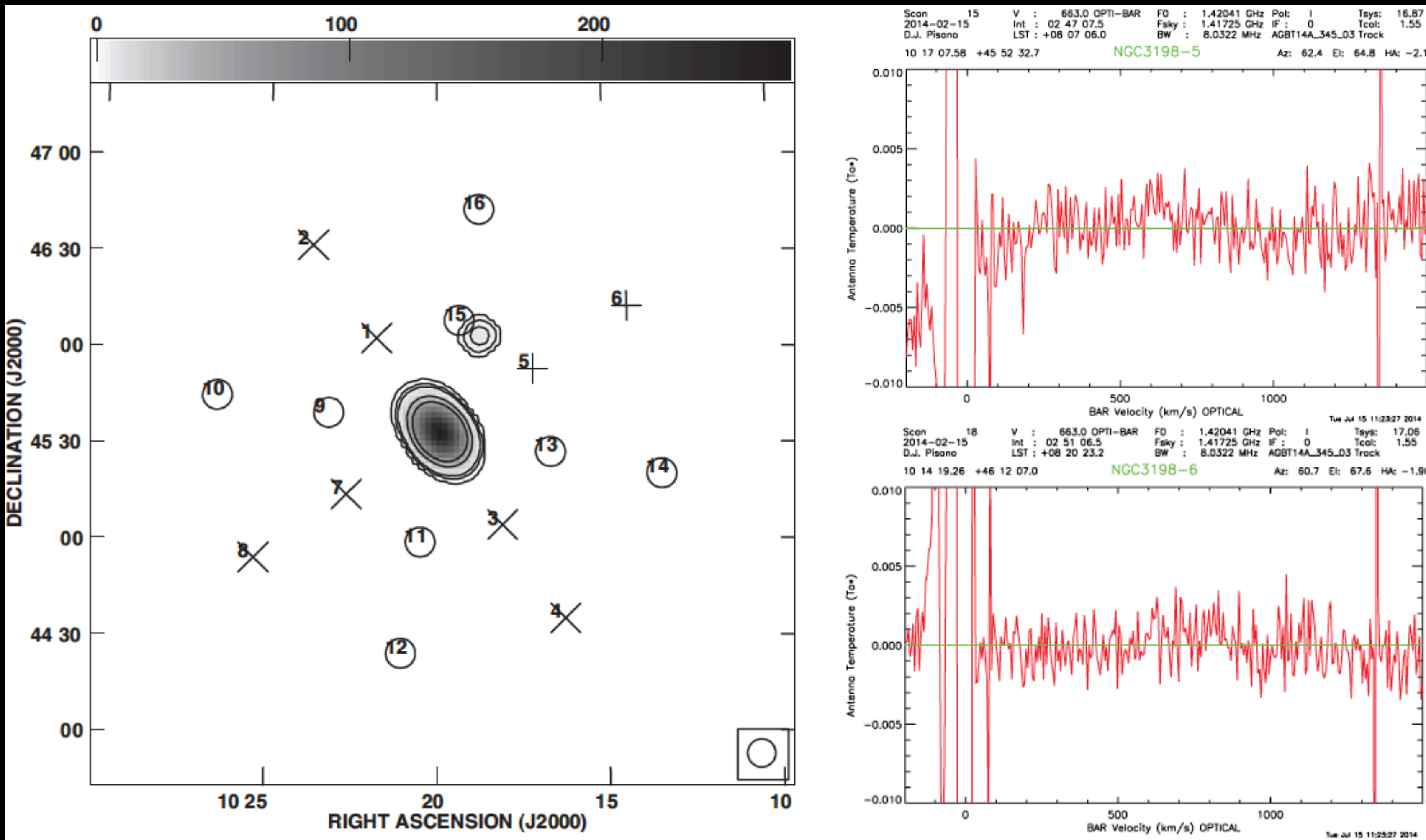
NGC 2403: Going even deeper.





All of the emission away from NGC 2403 is associated with the Milky Way.

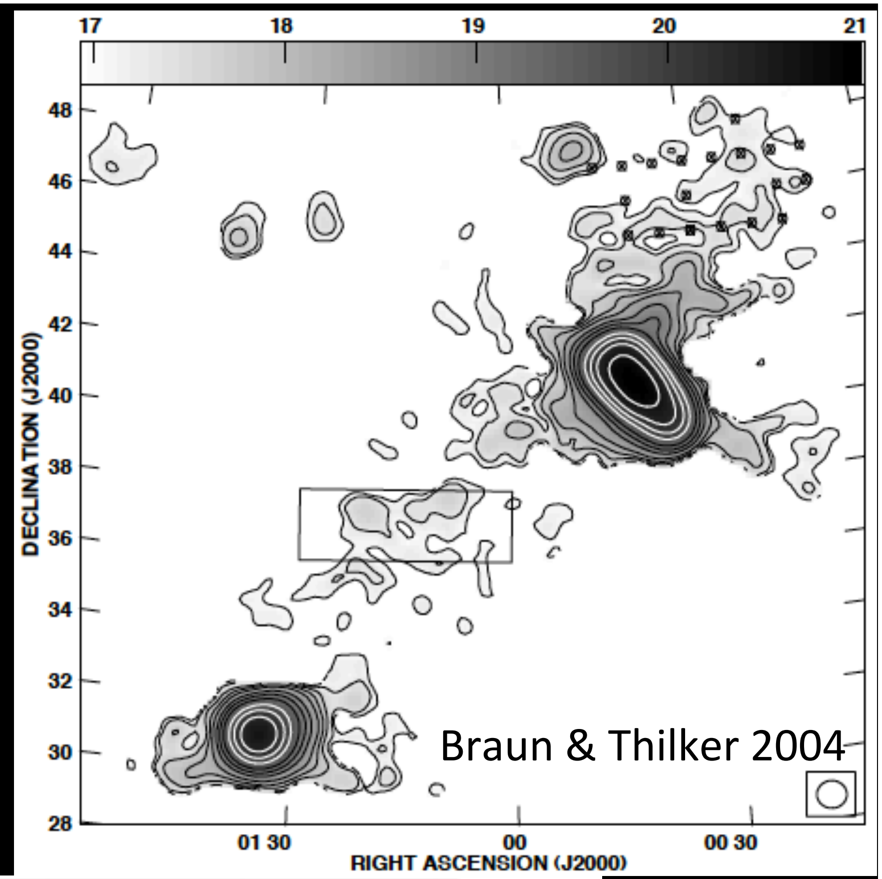
NGC 3198: Going even deeper

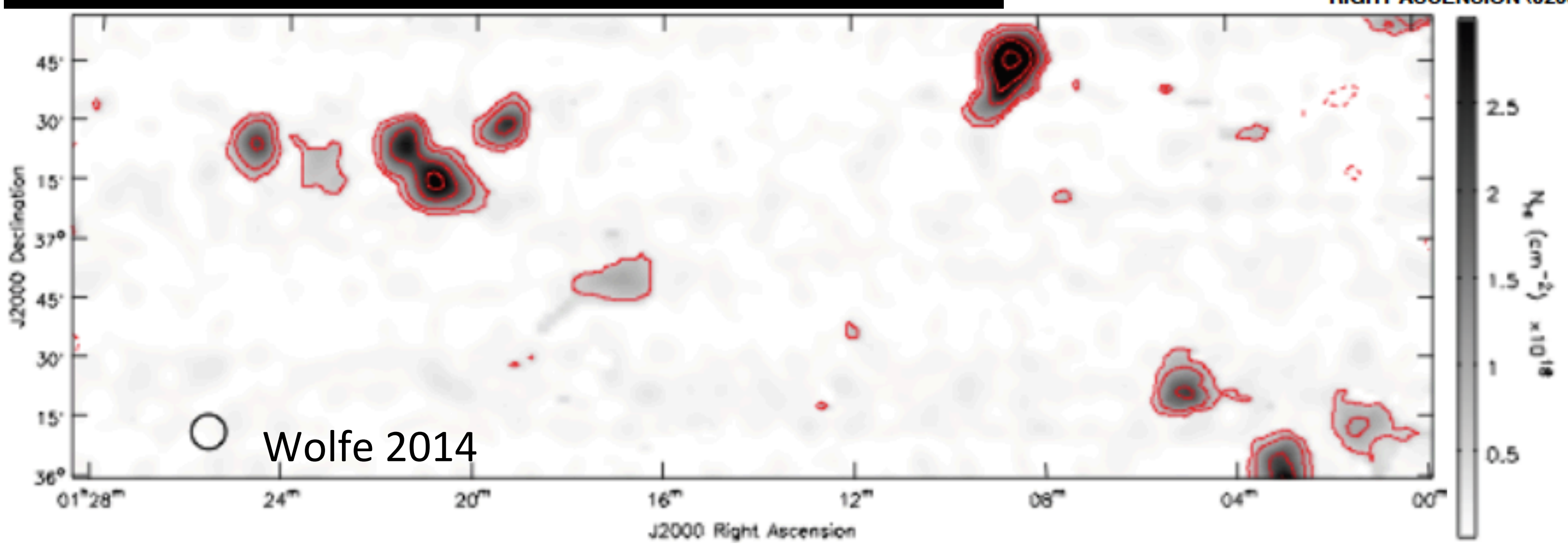


Barely any sign of HI at 10^{17} cm^{-2} around NGC 3198.

Around M31…

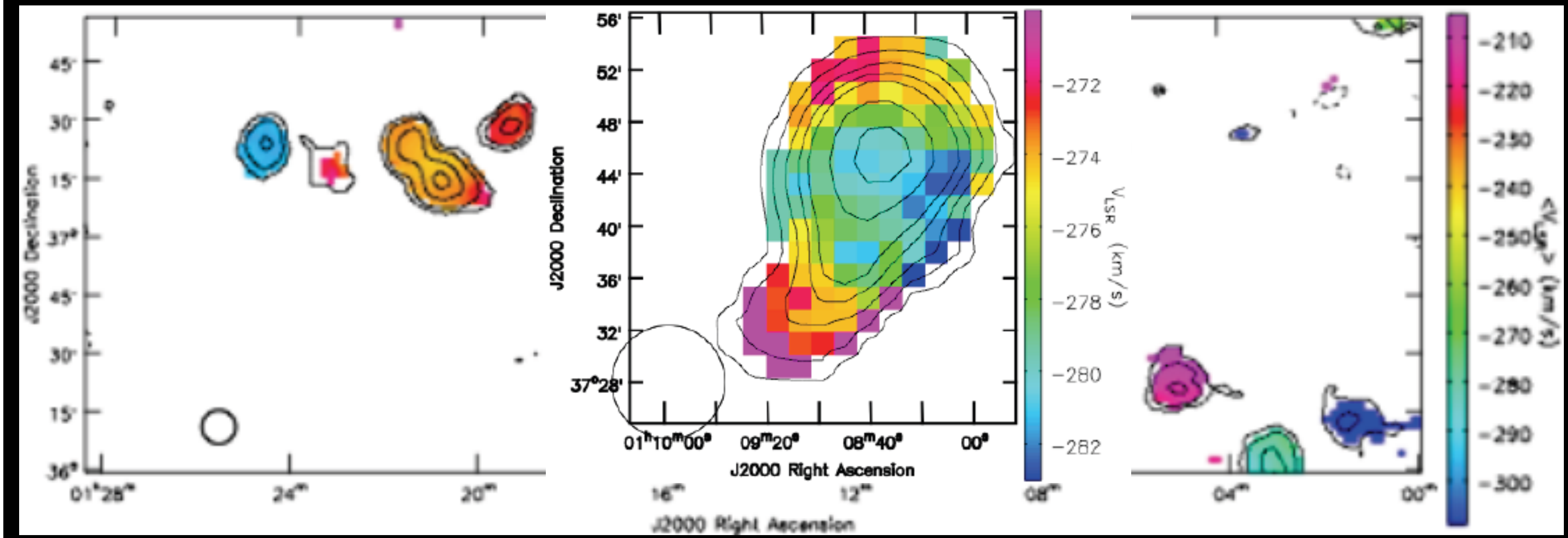
- Despite its initial appearance in BT04, even at $N_{HI} \sim 10^{17}$ cm^{-2}, this gas is still clumpy with $M_{HI} = 0.4\text{-}4\times10^{5}$ $M_{\odot}$.



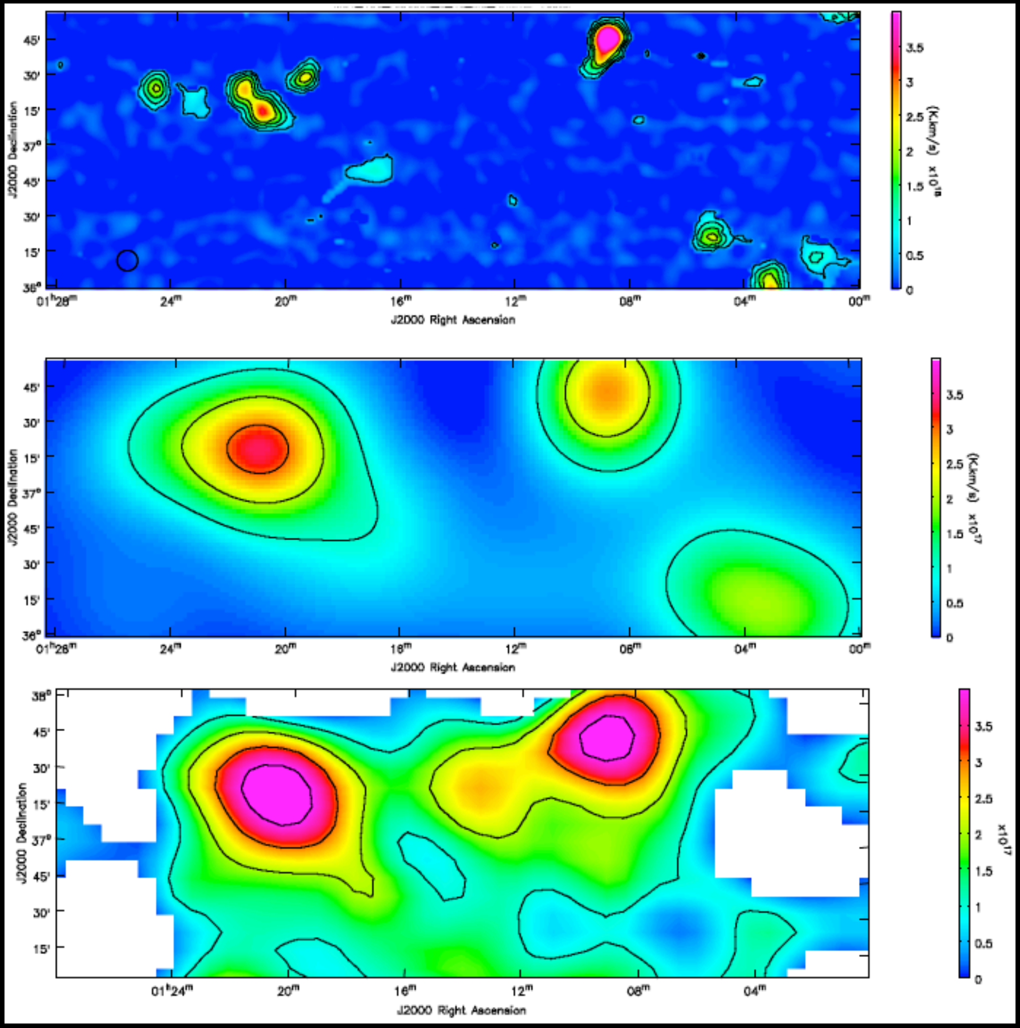


Clouds around M31

- Clouds have linewidths of ~20-30 km/s, and have very little internal velocity structure visible.



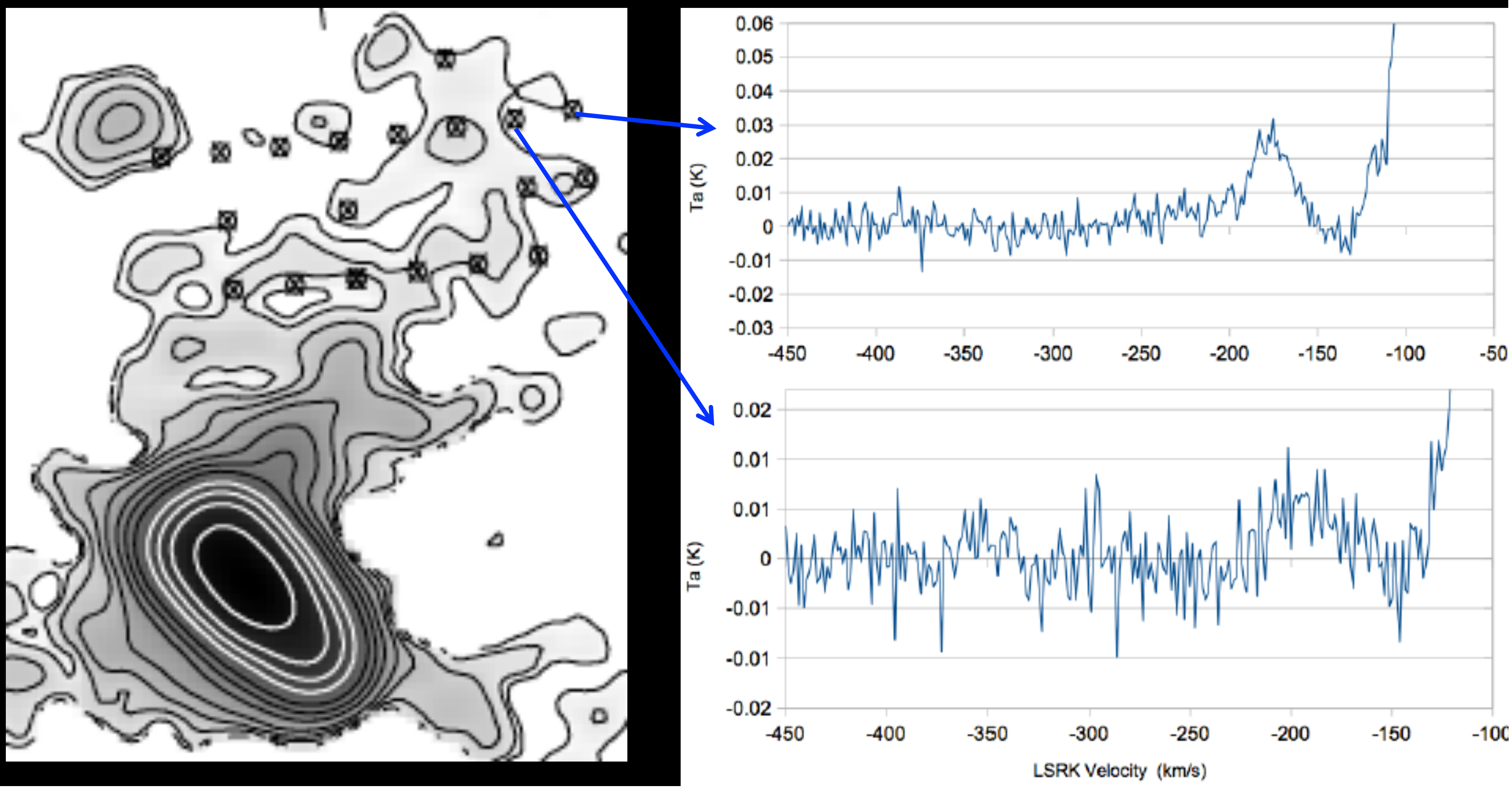
Comparing to BT04



- We recover all of the HI mass seen by BT04 in clouds, but we see different structures than they did.

Around M31…

- A grid of single pointings with the GBT to the NW of M31 reveal only sporadic HI at 10^{17-18} cm^{-2} (Wolfe 2014). This gas is still quite clumpy.



Conclusions

- GBT observations of HI down to $N_{HI} \sim 10^{18}$ cm^{-2} show that galaxies are more extended than expected from VLA/WSRT observations, and only a few have distinct low N_{HI} features (e.g. NGC 2403).
- Sparse grids and deep maps of HI down to $N_{HI} \sim 10^{17}$ cm^{-2} show covering fractions of ~12%, much lower than expected from Lyman α absorption line statistics or lower resolution 21 cm HI maps.
- This implies that HI is both clumpy and/or filamentary in nature, at least around nearby galaxies.
- Deeper maps are needed to confirm this result. May be possible with MHONGOOSE.