A GBT Survey of the HALOGAS Galaxies: Revealing the full extent of HI around spirals

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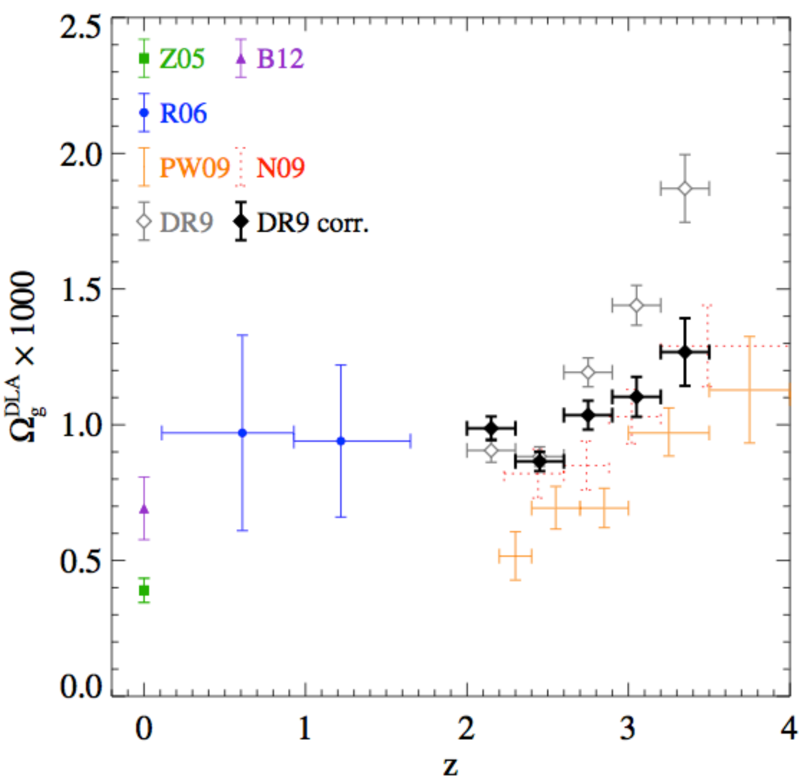
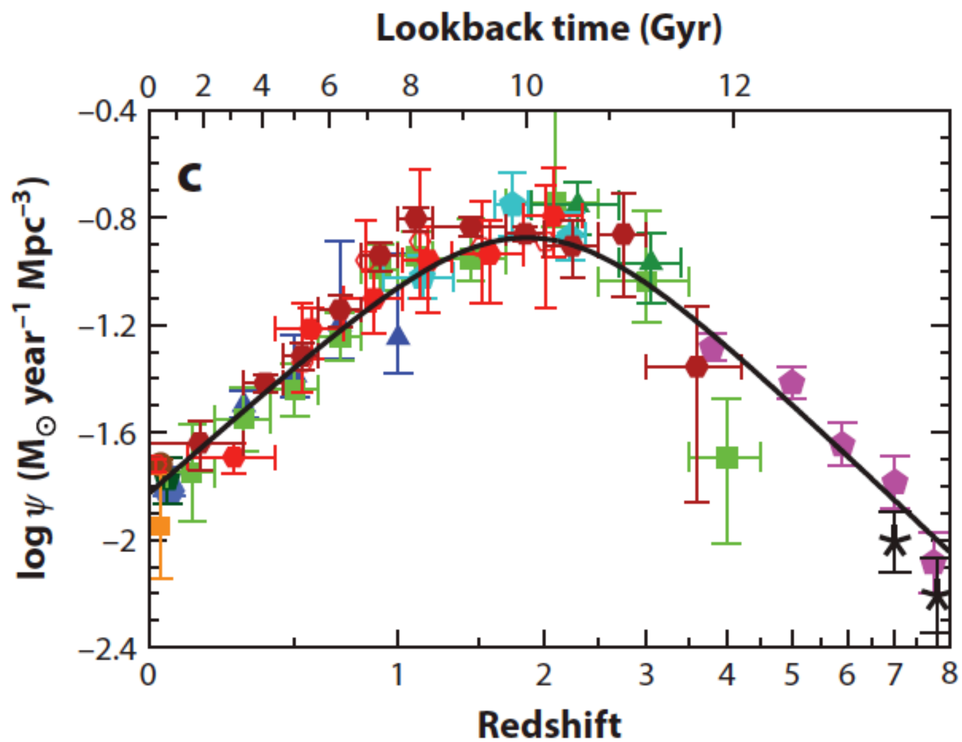
HI content vs. declining SFR



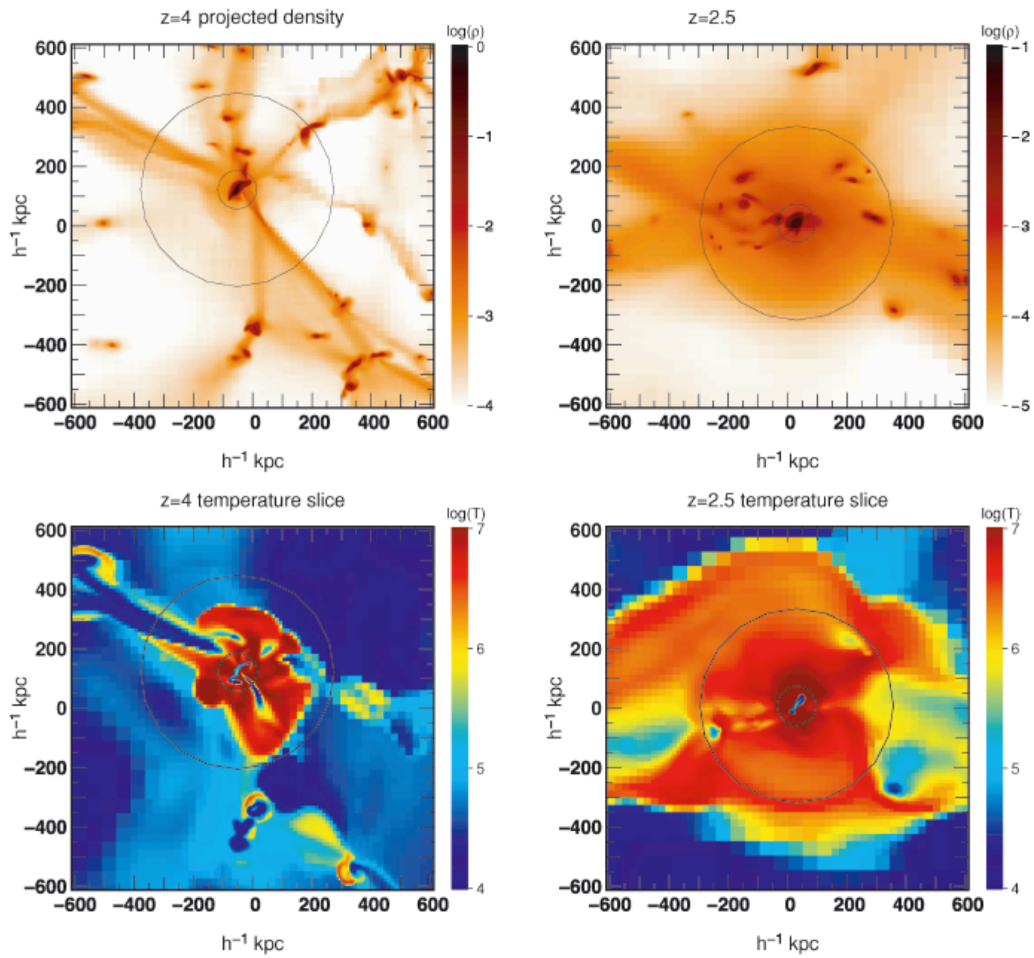
Noterdaeme et al. (2012)



Madau & Dickinson (2015)

Cold/Hot Mode Accretion (C/HMA)

- simulations predict gas is accreted onto galaxies in a bimodal process (Birnboim & Dekel 2003; Nelson et al. 2013; Keres et al. 2005, 2009)
- Cold mode should be evident in galaxies with $M_{halo} \leq 10^{11.4}\ M_{\odot}$ and $n_{gal} \leq 1\ h^{-3}\ Mpc^{-3}$ (Kereš et al. 2005).



Ovcirk, Pichon & Teyssier (2008)

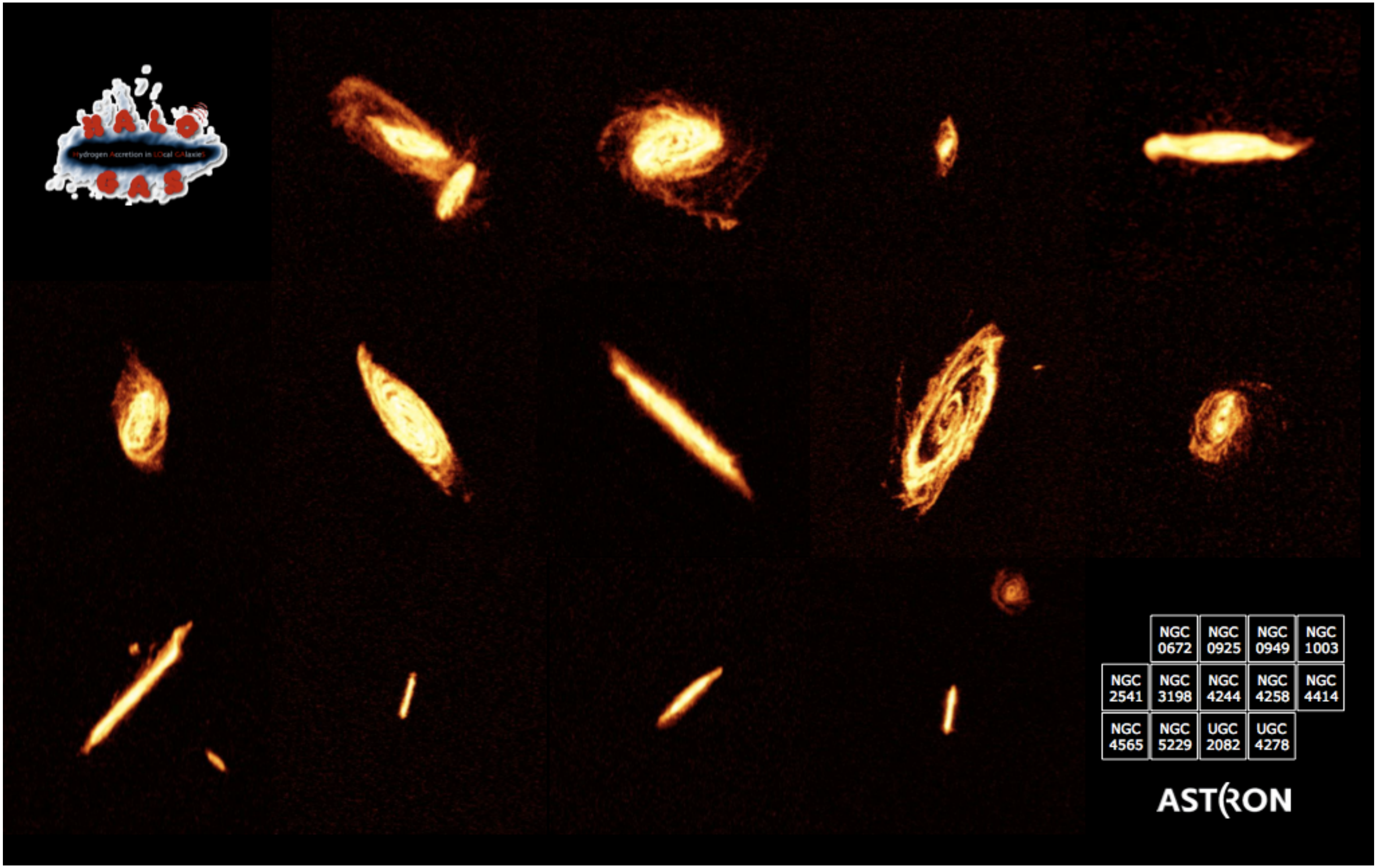
Observational Signatures of CMA

- Observational evidence is extremely limited!
  - Ribaudo et al. (2011) argue a detection in absorption
    - Require strong background sources
    - No info on extended spatial distribution
  - Large HI structures either related to accretion or tidal interactions around nearby galaxies
- high ionization fraction at $\log(N_{HI}) \leq 19.0$ cm^{-2}.
    - gas can cool enough to form HI clouds within the inner-most regions of the halo (Joung et al. 2012)
    - should be detectable at $\text{Log}(N_{HI}) \sim 18$ cm^{-2}

HALOGAS Sample

- Representative sample of spiral galaxies
  - **24 total** Barred and unbarred spirals
  - Systemic velocities > 100 km/s to avoid MW HI signal
  - Sample spans wide range of SFRs,warps/ lopsidedness, HI Mass, Stellar Mass, M_{dyn}, environment etc…
- Goals for complete HI census using the GBT
  - Build up large number statistics pertaining to galaxy properties
  - Look for signatures of direct accretion of cold gas from the IGM
  - Have info at ALL angular scales (short spacing correction).

HALOGAS Sample (Heald et al. 2011)



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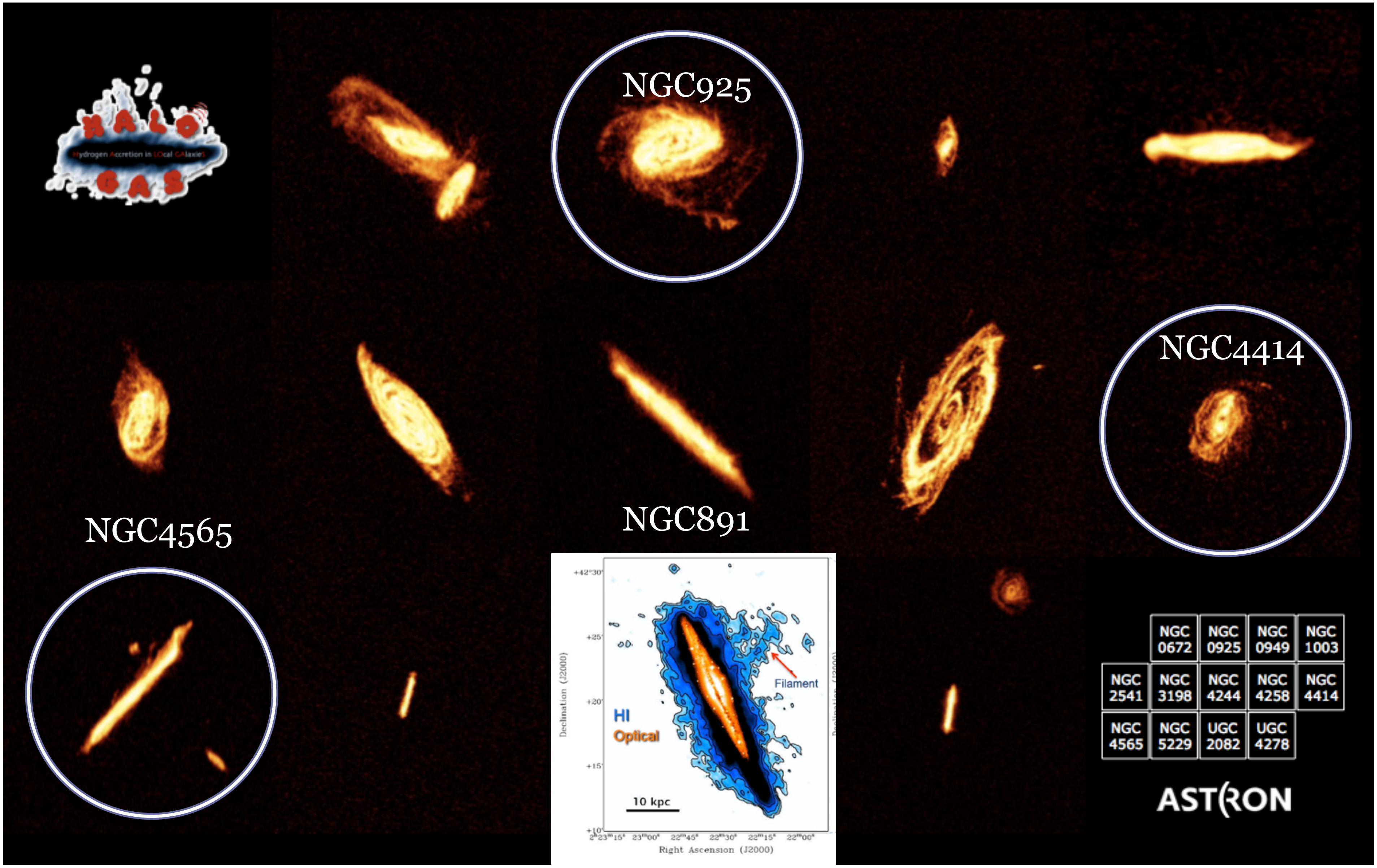
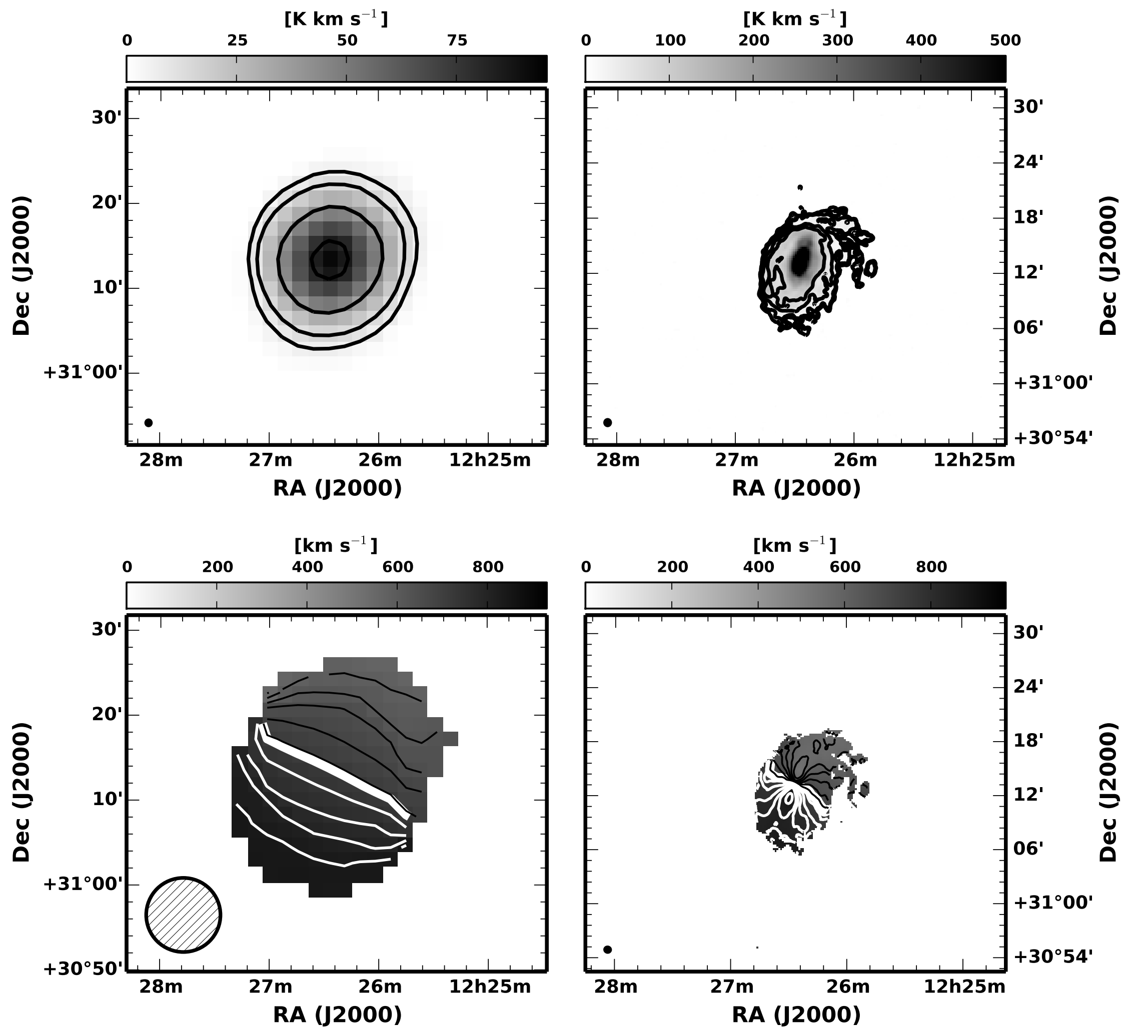


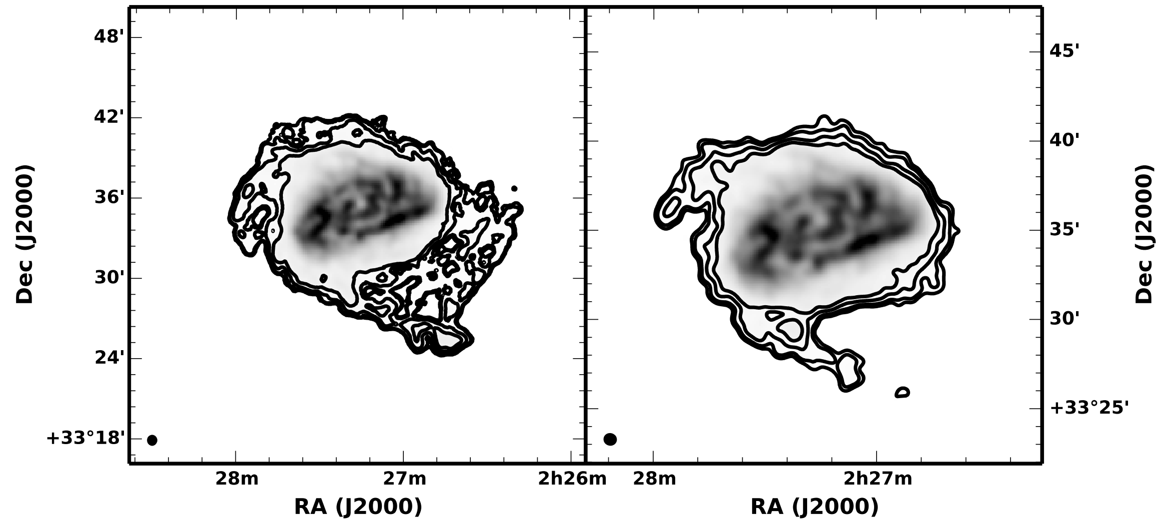
Summary of GBT Observations

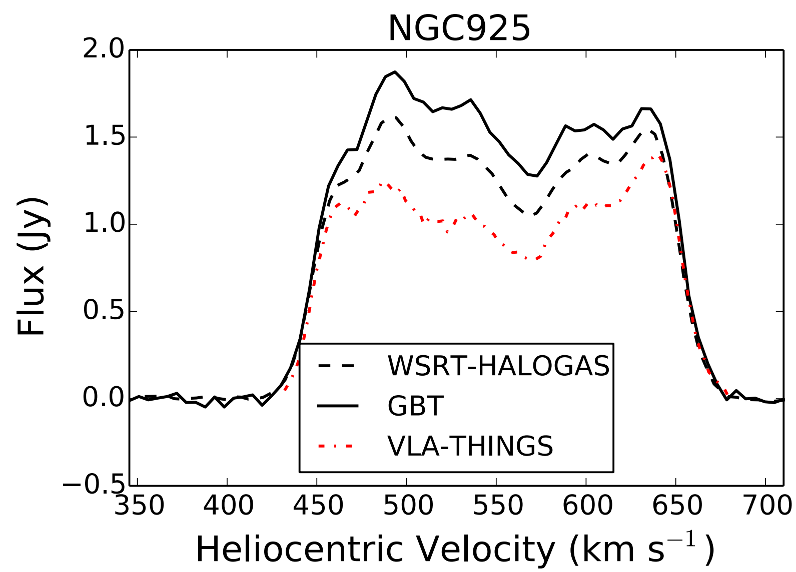
- Minimum of 10 hours per source.
- Mapped in basket-weave fashion over 4+ deg^2 area
- Used map edges as 'off' position.
- 3σ N_{HI} over a 20 km/s line of about $2x10^{18}$ cm^{-2}.



Comparing VLA/WSRT (NGC925)

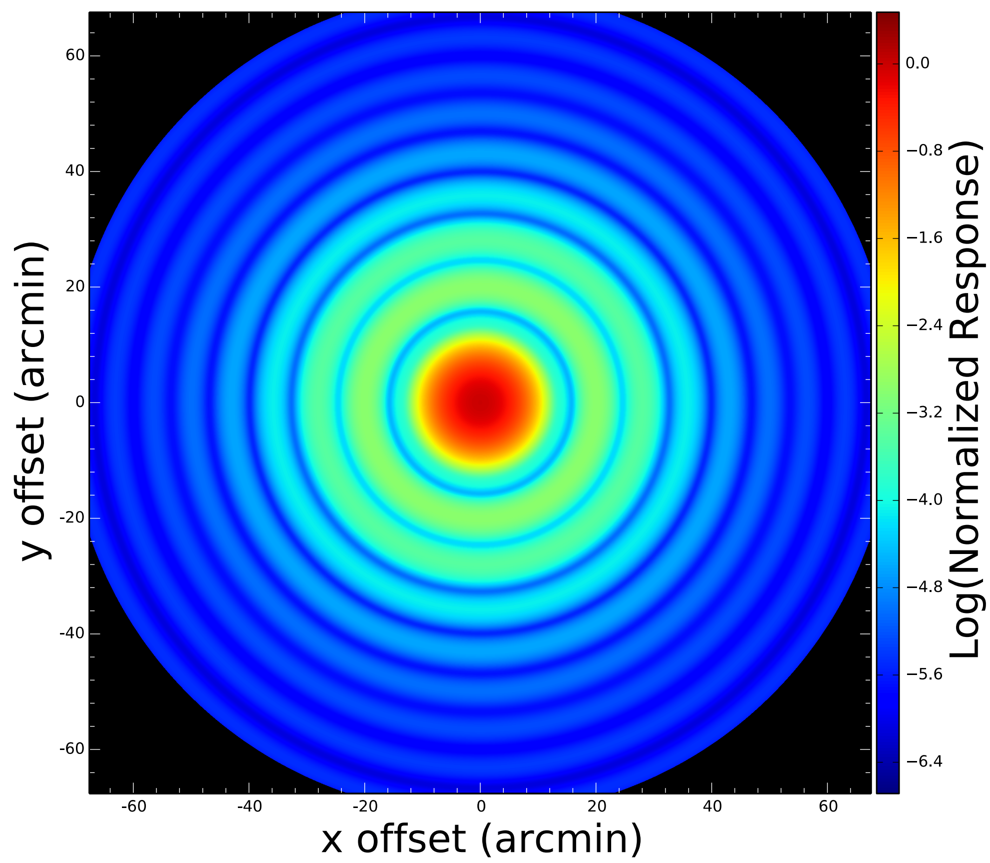
- VLA-THINGS smoothed to WSRT resolution (38''x33'').
- WSRT data are 5x more sensitive
- Extended structure is ~26 kpc in extent.





Convolved WSRT Maps

- Use model beam map to account for “stray” radiation coming into the near sidelobes.
- theoretical calculation of the GBT beam Srikanth (1993).

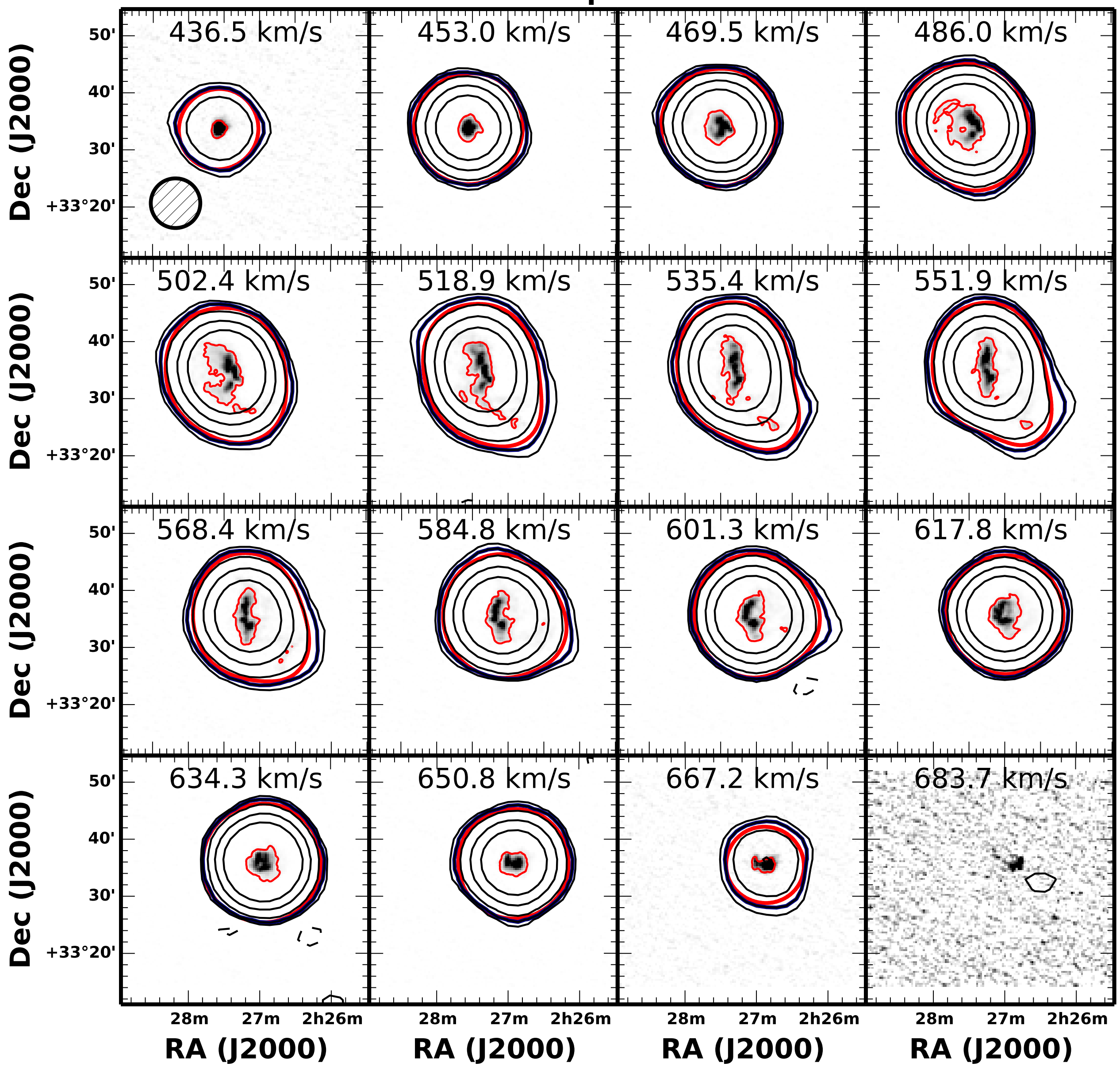


KEY:

GBT data: thick $7e17\ cm^{-2}$ (5σ) & thin contours

WSRT data: thin ($1e19\ cm^{-2}$ & thick (set at $7e17\ cm^{-2}$; same 5σ level as GBT!) red contours

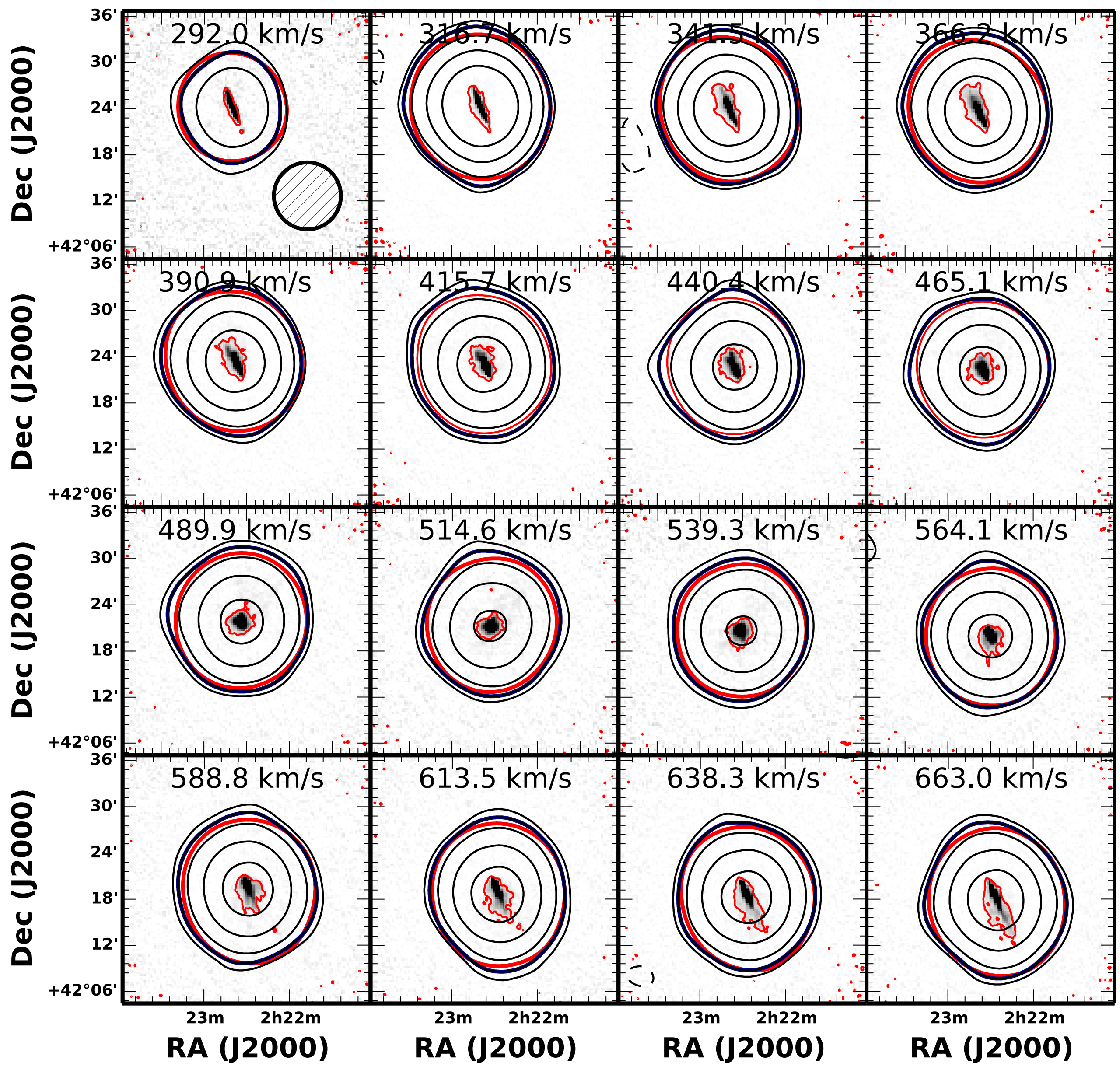
Channel Maps of NGC925



-We detect more flux overall in the GBT maps and out to larger extents.

Channel Maps of NGC891

KEY:
GBT data: thick 4.8e17 cm^{-2} (5σ) & thin contours
WSRT data: thin (1e19 cm^{-2} & thick (4.8e17 cm^{-2}) red contours

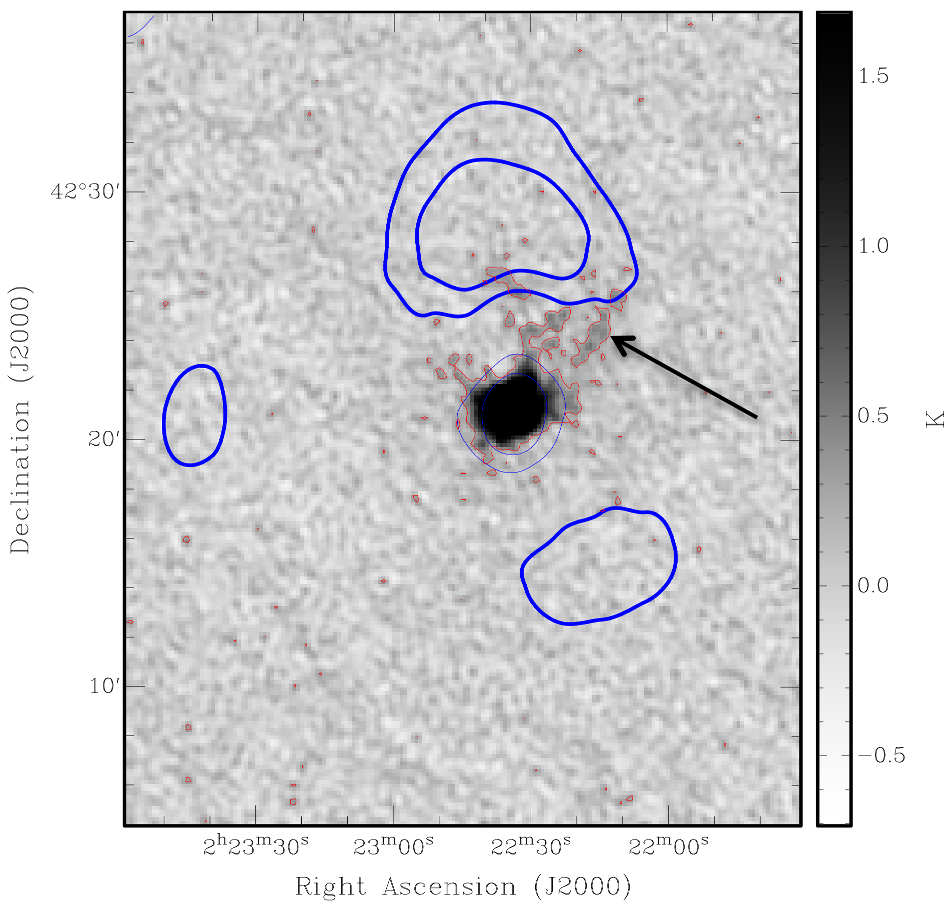


- We again see the GBT detects HI out to larger extents.

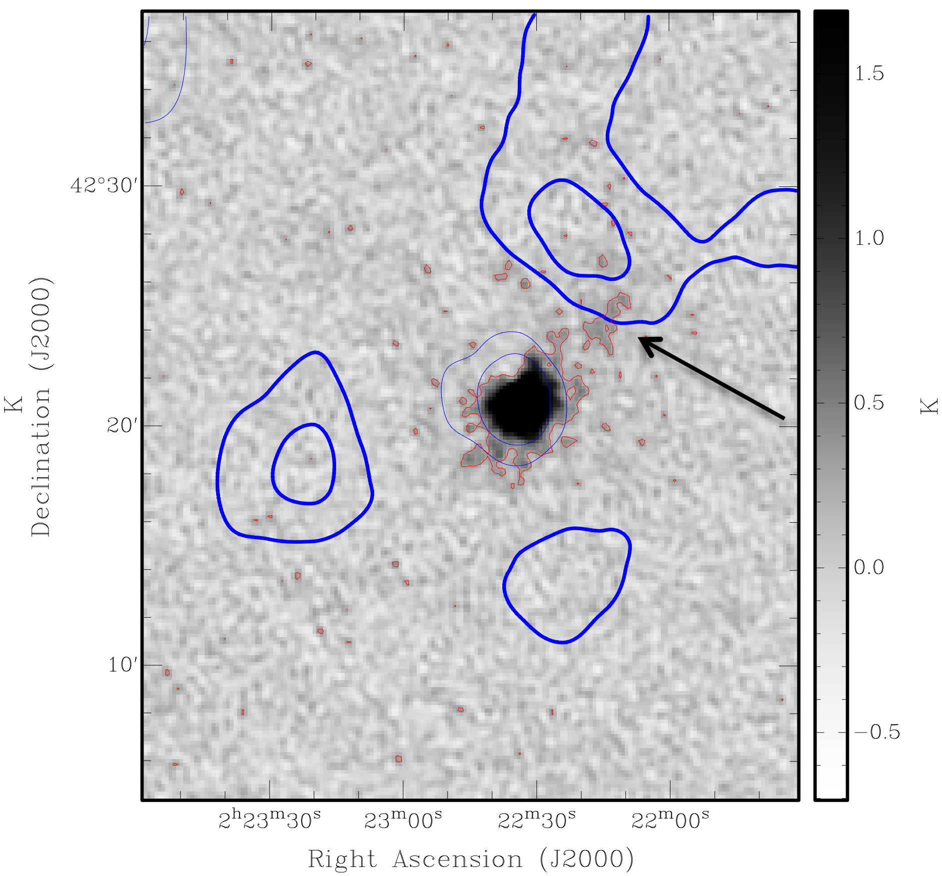
What can the residual maps show us?

NGC891

507 km/s



523 km/s



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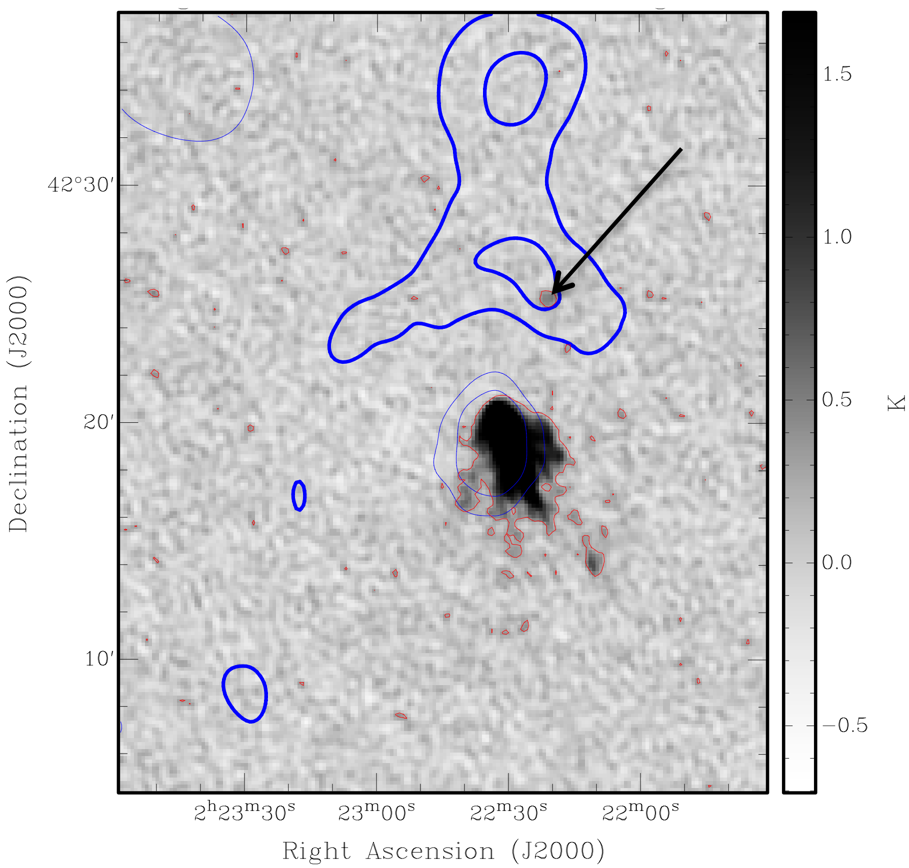
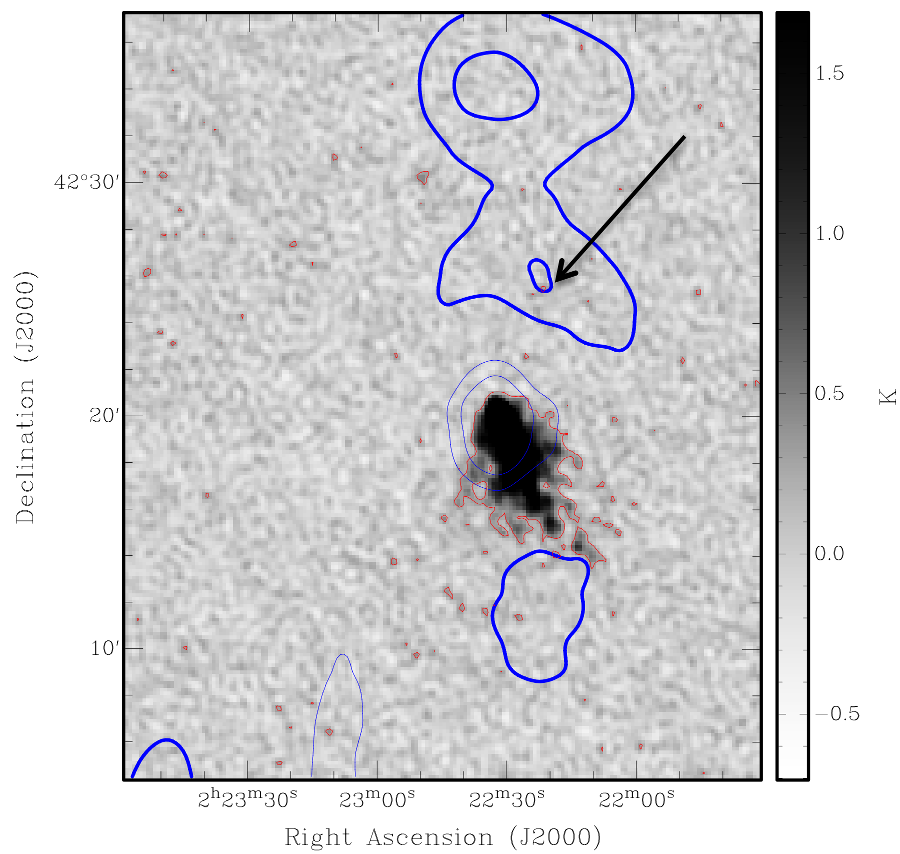
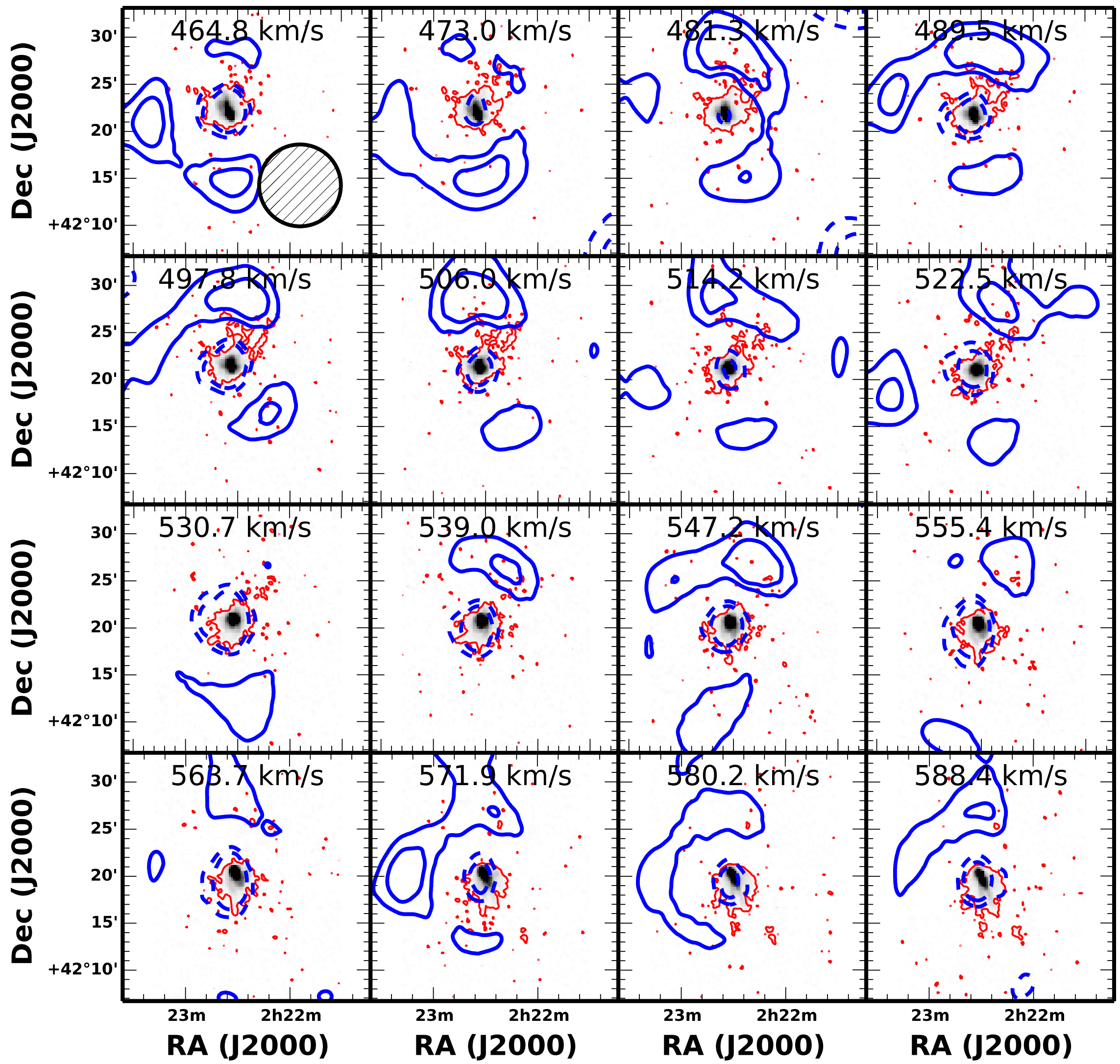


613 km/s



What can the residual maps tell us?

- 2 and 3σ signal traces filament/ clouds spectrally & spatially
- Morphology is similar to what cold flows would take in emission.

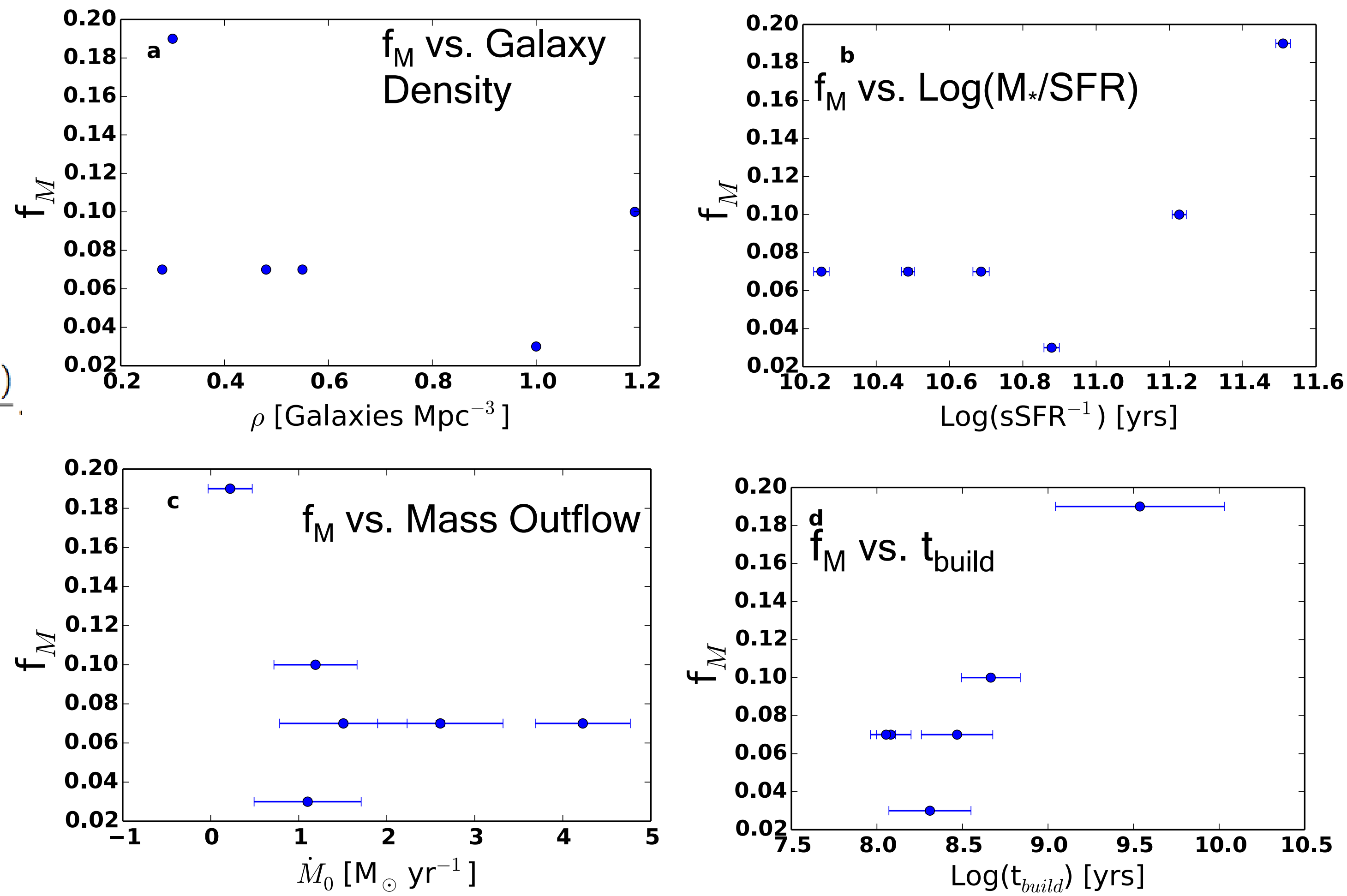


Relating HI to Intrinsic Galaxy Properties

- These GBT observations reveal extended, diffuse HI reservoirs around these sources.
- Even small amounts of excess HI likely trace abundant ionized hydrogen around individual galaxies.
- What are the possible origins of the HI detected by the GBT?
  - Tidal interactions with companion
  - Accretion from the IGM
  - Outflows

Relating HI to Intrinsic Galaxy Properties

$$f_M = \frac{(M_{GBT} - M_{WSRT})}{M_{GBT}}.$$



$$t_{build} = \frac{M_{GBT} - M_{WSRT}}{\dot{M}_0}$$

Relating HI to Intrinsic Galaxy Properties

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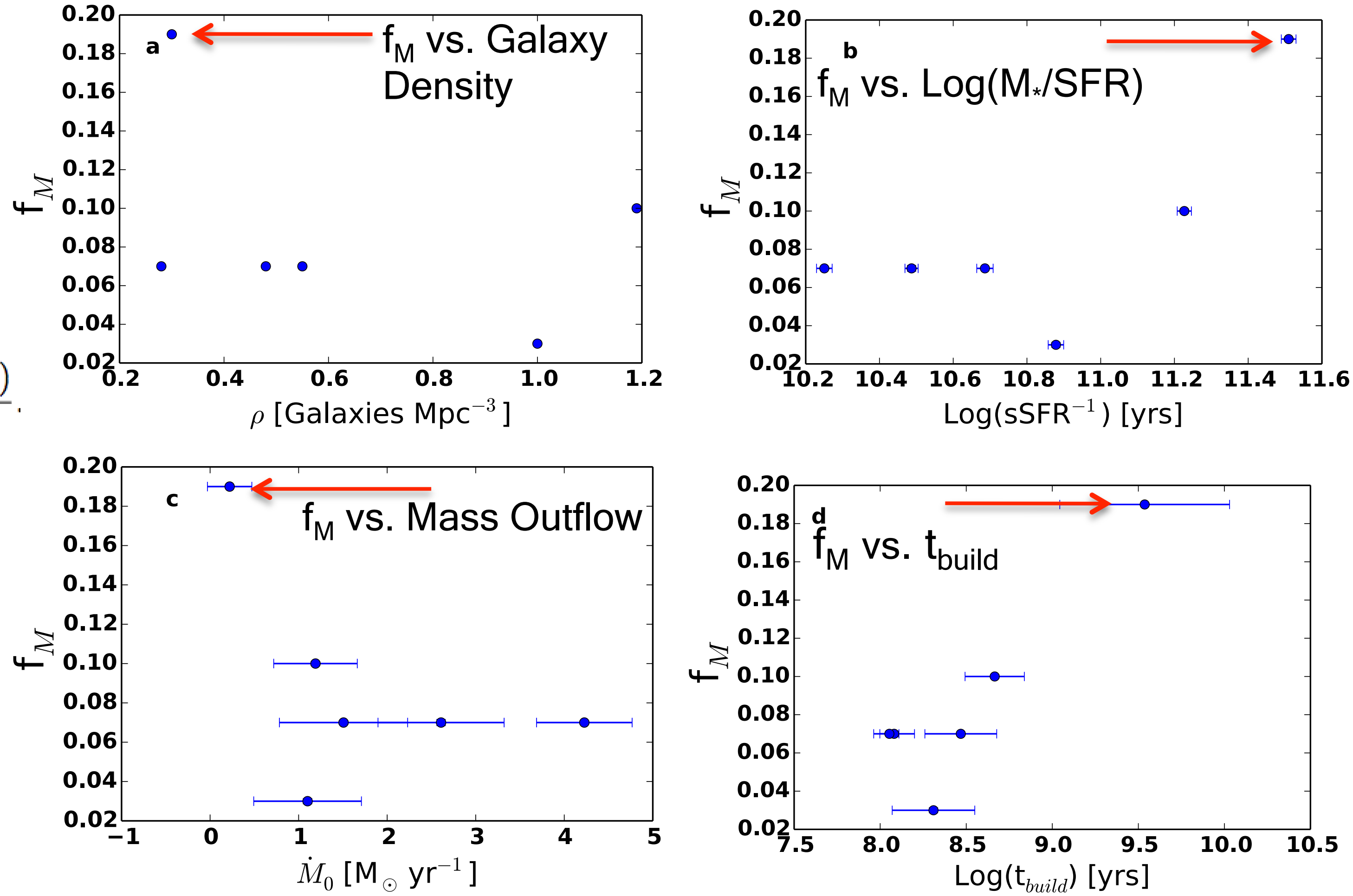
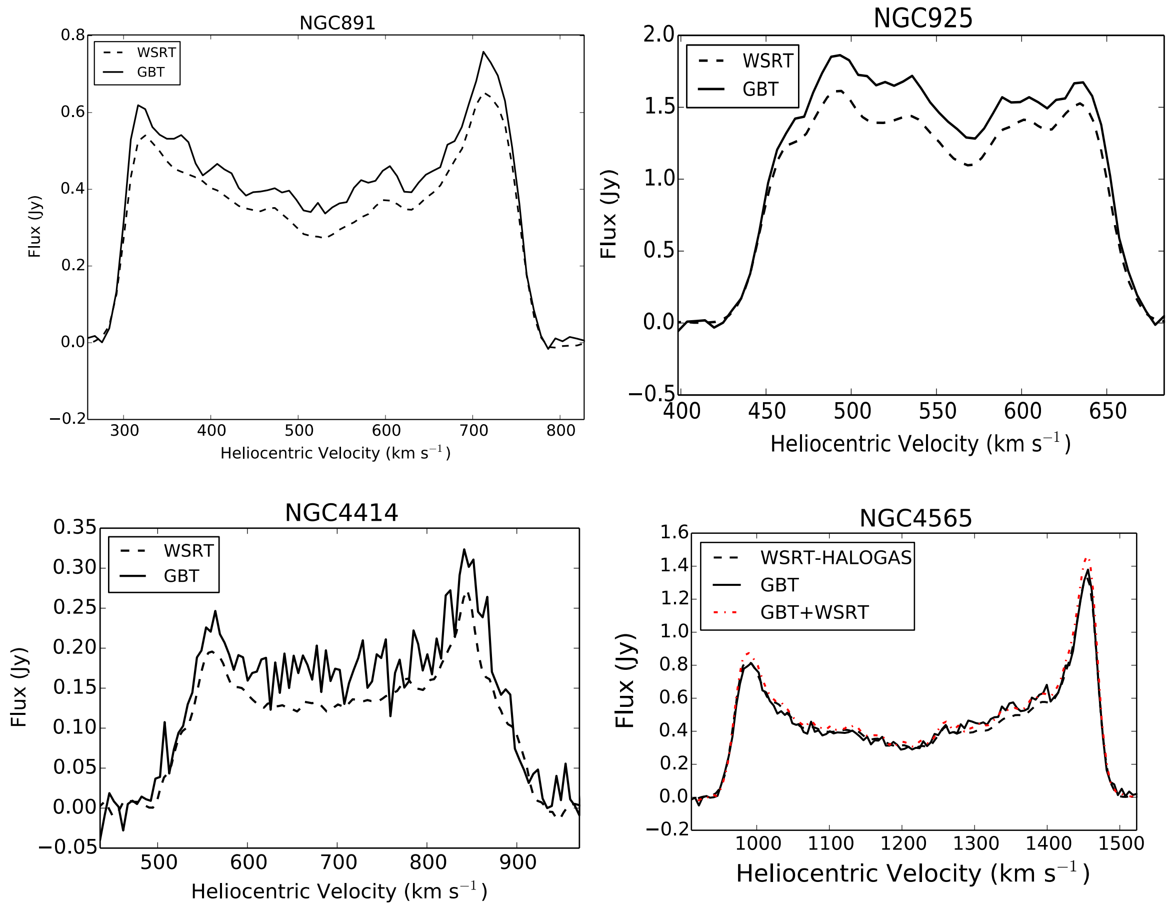


$$t_{build} = \frac{M_{GBT} - M_{WSRT}}{\dot{M}_0}$$

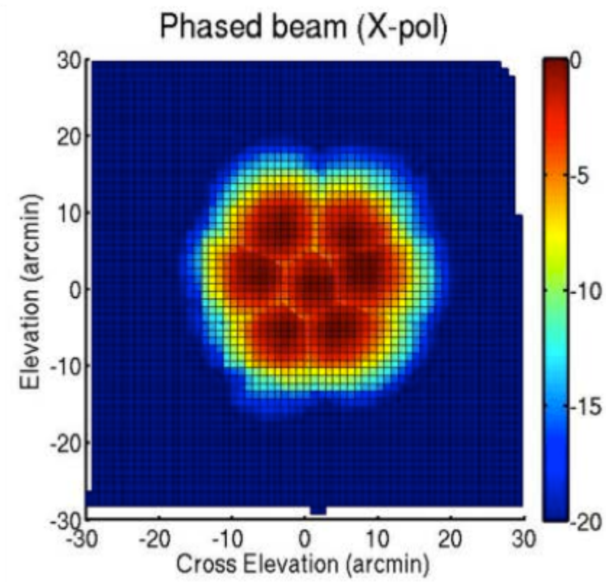
Results so far (4/24 Sources)

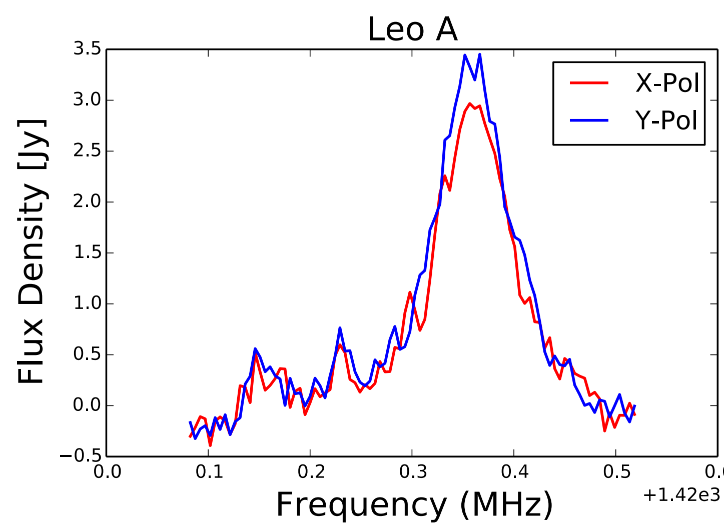
- GBT observations reveal extended, diffuse HI reservoirs
- Signal in residual maps trace interesting HI features
- on average, the GBT detects ~10% more HI than the WSRT



Focal L-band Array for the GBT (FLAG)

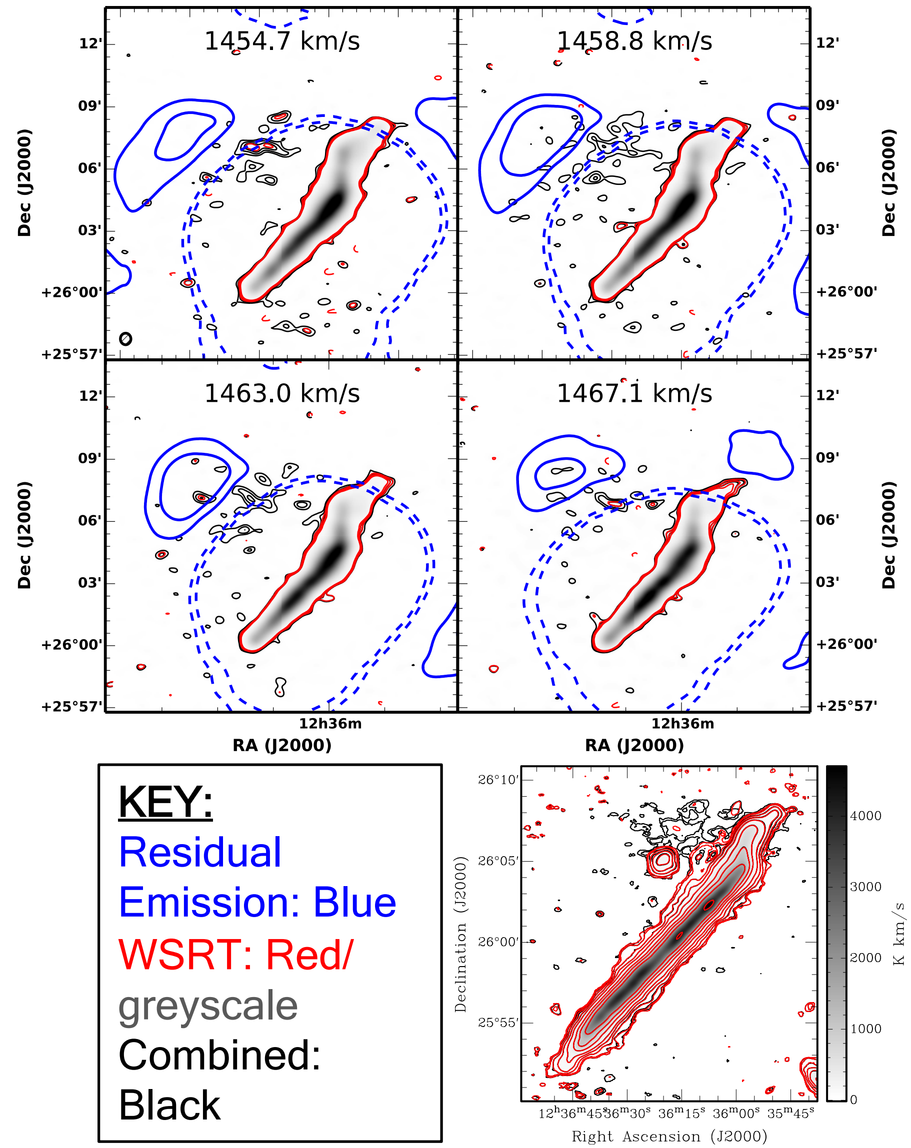
- Backend for cryogenic phased array feed (PAF)
- Increase survey speeds by a factor of 3-5 by forming multiple beams on the sky.
- Currently, WVU is working alongside NRAO and BYU to have the PAF and backend to be ready in 2016.





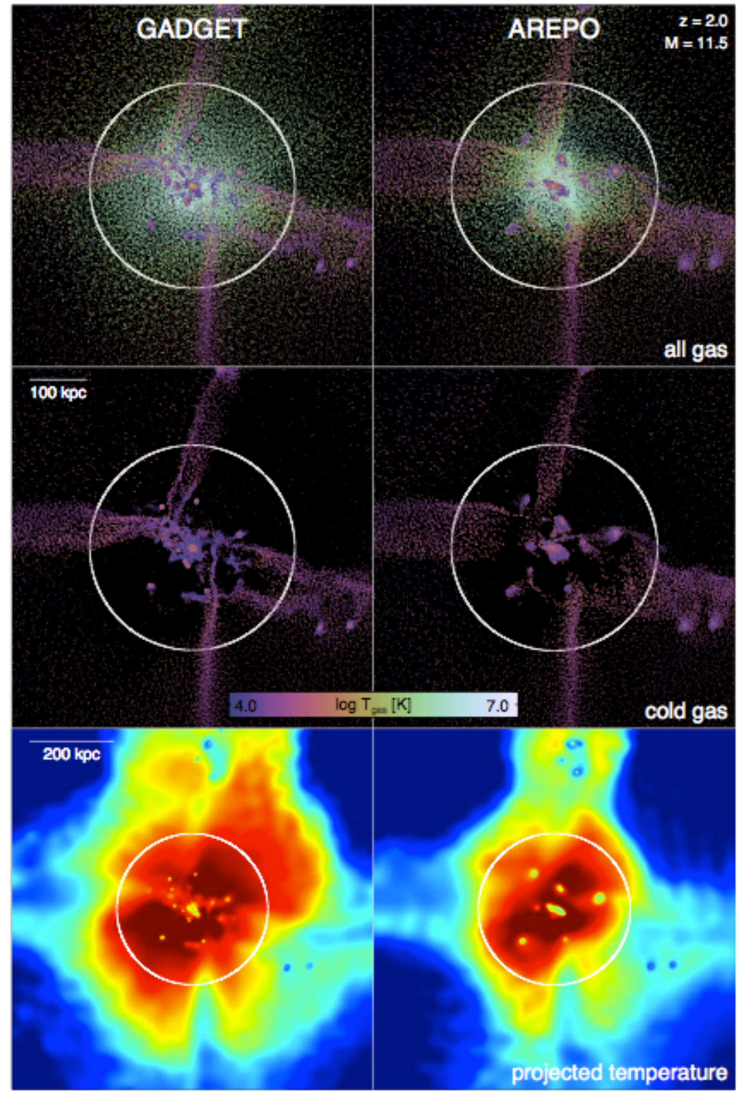
NGC4565

- On the other hand, we can also confirm *lack* of extraplanar HI (Zschaechner et al. 2012).
- Combining WSRT +GBT via the Fourier domain yields (small) enhancements of noisy features
- coincident with signal in residual map



Cold*/Hot Mode Accretion

- Morphology and accretion rate differ between SPH vs. AMR simulations (Nelson et al. 2013)
- Differences in morphology due to varying angular momentum reservoir.
- Differences in accretion rate arise from numerical artifacts in the SPH codes, and more efficient cooling in AMR simulations.
- Observational constrains are needed as a benchmark for simulations.



Nelson et al. (2013)