A GBT Survey of the HALOGAS Galaxies: Revealing the full extent of HI around spirals and searching for signatures of cold mode accretion

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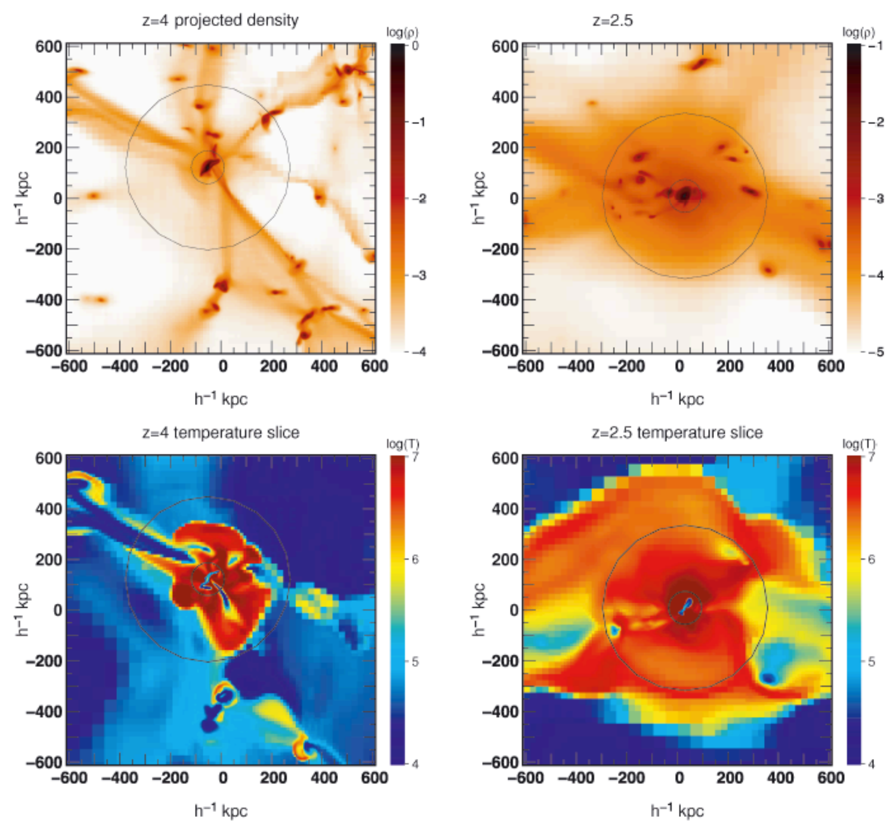
Cold*/Hot Mode Accretion

- Numerous simulations predict gas is accreted on to galaxies in a two dominant processes (Birnboim & Dekel 2003; Keres et al. 2005, 2009)
- Filamentary cold mode is most dominant at $z<1$; at $z=0$ the quasi-spherical hot mode becomes dominant for galaxies with high mass halos and in high density environments
- Cold mode is still dominant through $z=0$, though should only 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)

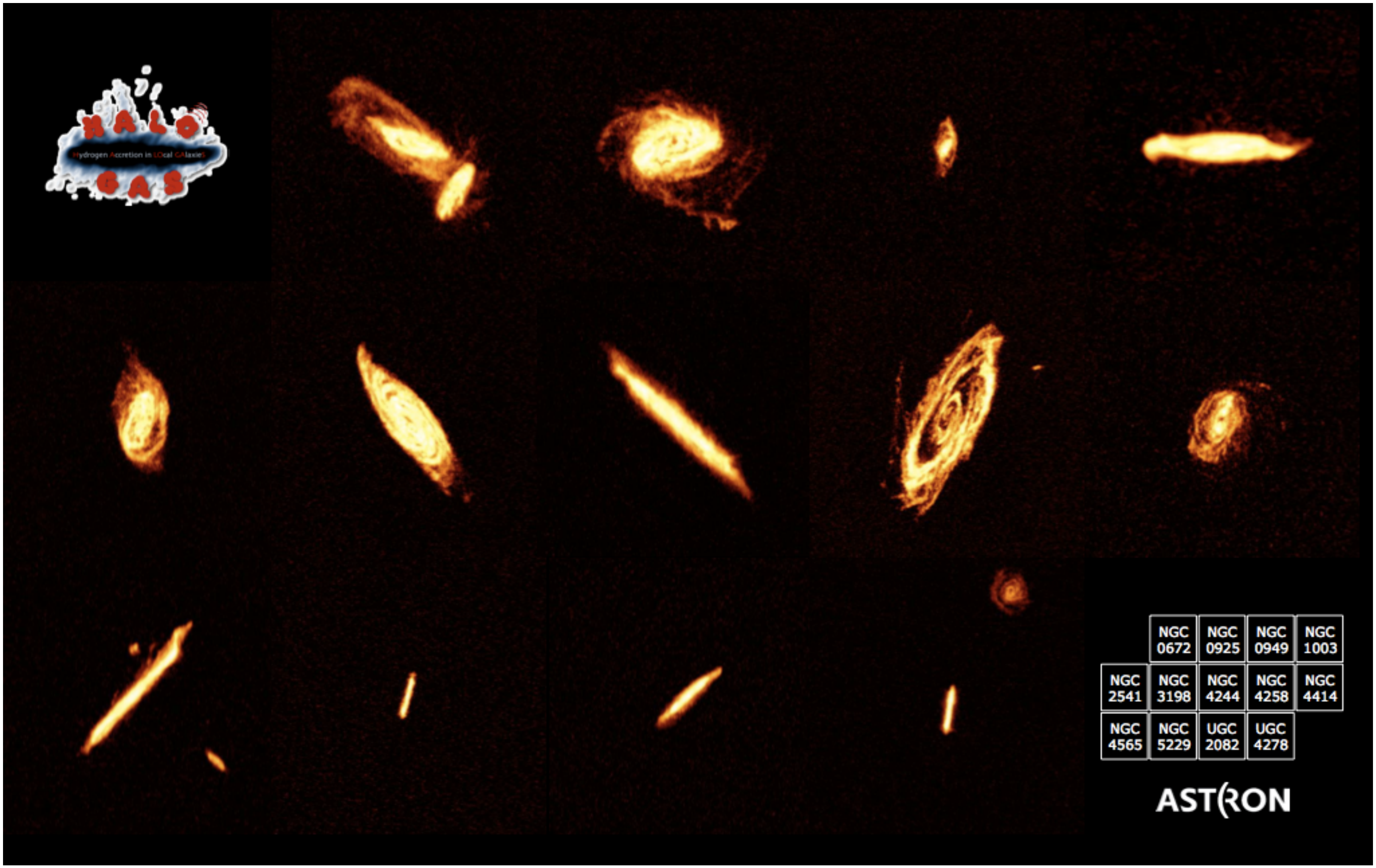
Observational Signatures

- Observational evidence is extremely limited!
  - Ribaudo et al. 2011 argue a detection in absorption from obs of Lyman-Limit Systems.
    - require serendipitous quasars or other strong background sources.
    - No info on extended spatial distribution.
  - Braun & Thilker (2004) discovered low density HI filament connecting M31 & M33. Wolfe et al. 2013 found this filament to be made of clumpy HI.
  - Bekki (2008) and Putman et al. (2009) propose this filament is of tidal origin.
  - Pisano (2014) and de Blok et al. (2014) discovered large HI structures in NGC6946 and NGC2403, which are either related to accretion or tidal features.
- Detection in emission is extremely difficult due to high ionization fraction at $\log(N_{HI}) \leq 19.0\ cm^{-2}$.
    - Simulations by Joung et al. (2012) show gas can cool enough to form HI clouds within the inner-most regions of the halo (R <100 kpc)
    - should be detectable at $\mathrm{Log}(N_{HI}) \sim 18\ cm^{-2}$

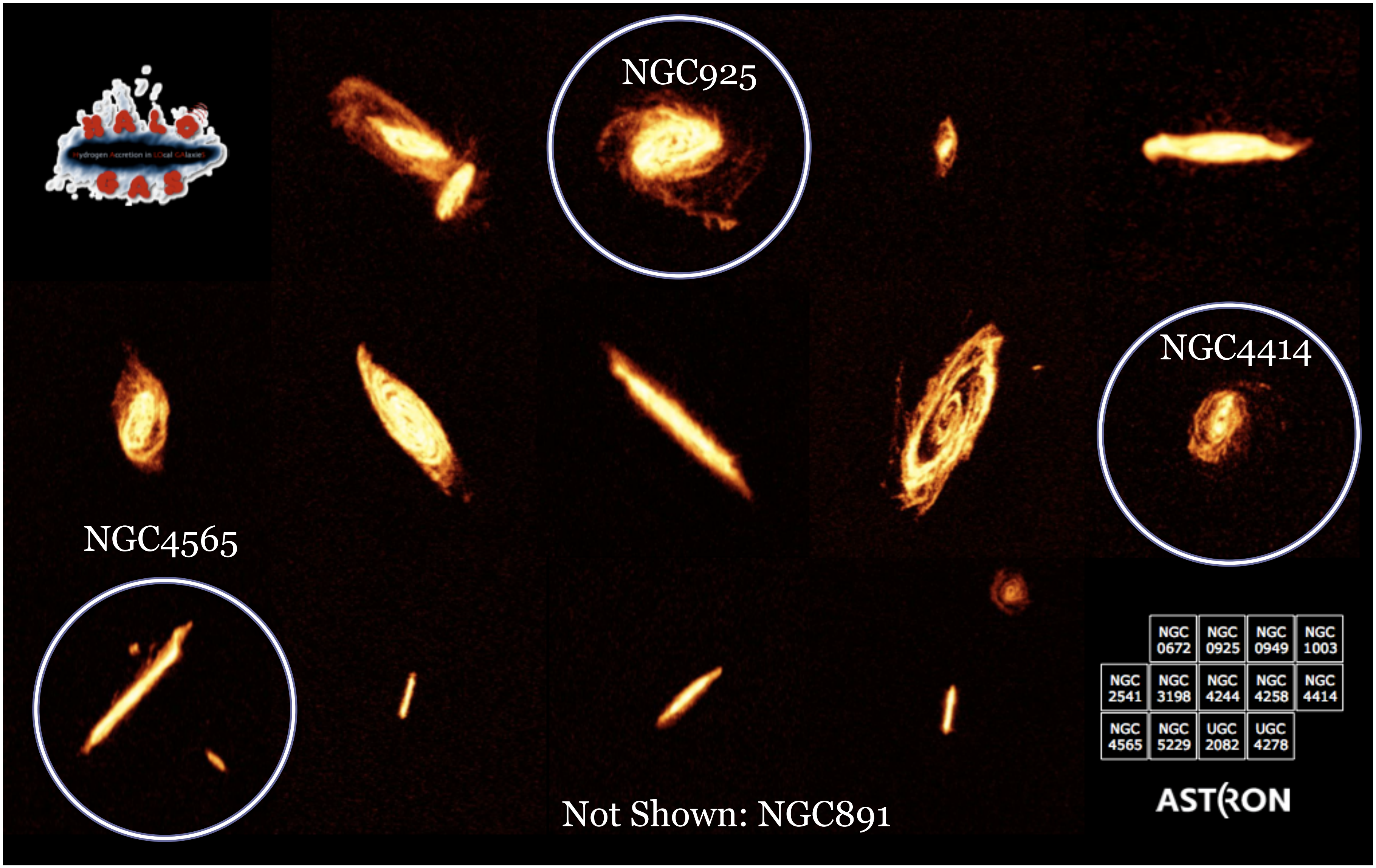
HALOGAS Sample

- Representative sample of spiral galaxies
  - **24 total** Barred and unbarred spirals with Hubble types between Sa and Sd
  - Systemic velocities > 100 km/s to avoid MW HI signal
  - Inclination ranges from 50 to 90 deg
  - Sample spans wide range of SFRs,warps/ lopsidedness, HI Mass, Stellar Mass, M_{dyn}, environment etc…
- Study of the extraplanar gas kinematics will constrain key parameters predicted by halo gas and accretion models
- Perfect sample to use as the first **statistical** study relating galaxy properties and HI environment at and N_{HI}~10^{18} cm^{-2}.

HALOGAS Sample (Heald et al. 2011)

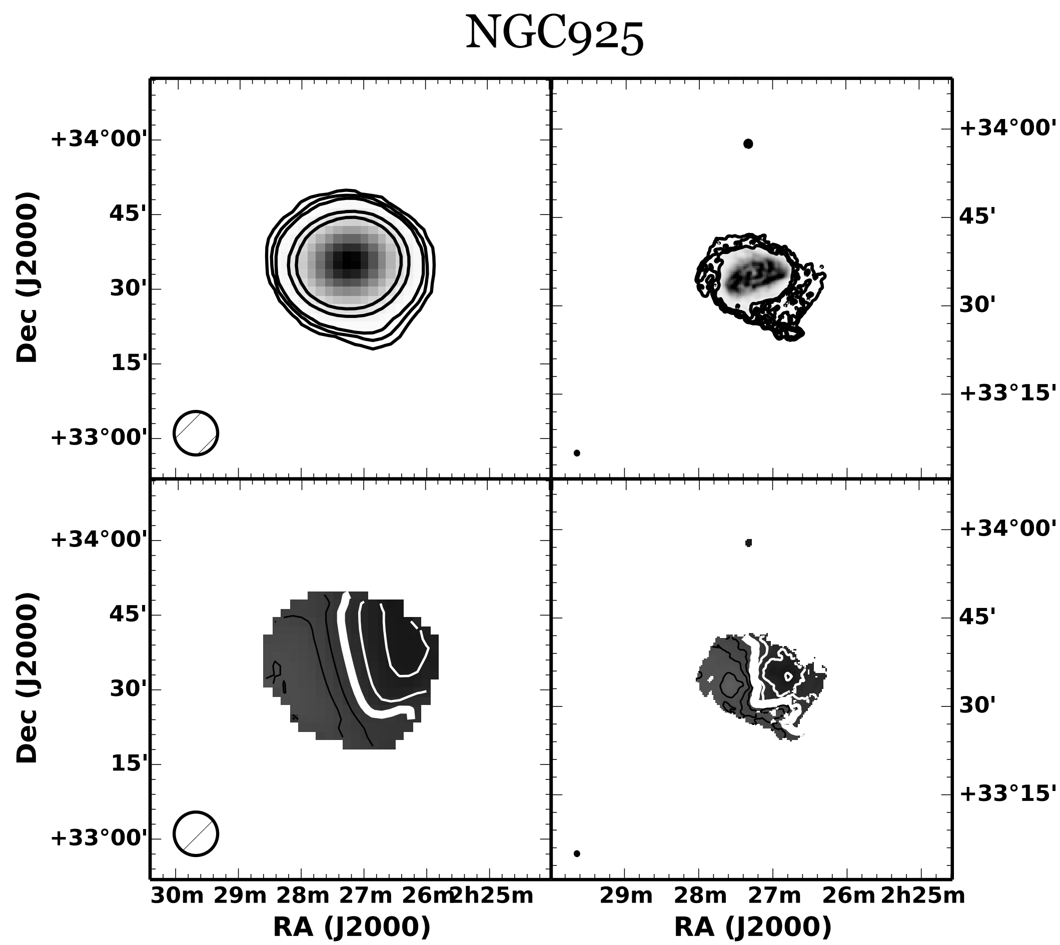


HALOGAS Sample (Heald et al. 2011)



Summary of GBT Observations

- Minimum of 10 hours per source.
- Mapped in basket-weave fashion over 4 deg^2 area
- Data taken frequency switched for calibration, though reduced differently.
- Used map edges as ‘off’ position near the edge.



Why supplement high-res data with single dish observations?

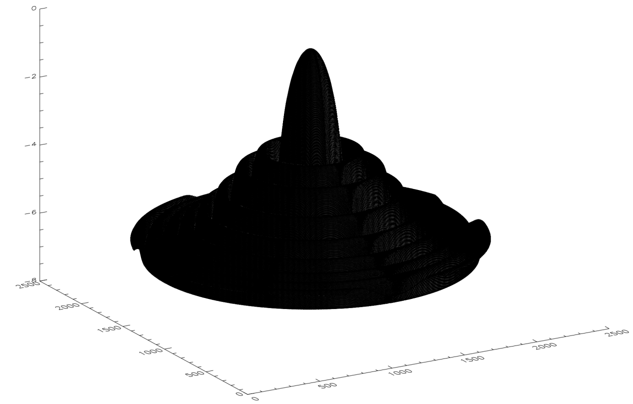
- Superior surface brightness sensitivity
  - Typical rms noise per 5.2 km/s velocity channel of 15 mK.
  - Corresponds to 3σ column density over a 20 km/s line of 1.7×10^{18} cm^{-2}
    - GBT is *a full order of magnitude* more sensitive than VLA (THINGS) and WSRT (HALOGAS)
    - Diffuse, extended HI component tracing theorized 'cold' flows *should* be detectable.
- Sensitive at ALL angular scales
  - Missing baselines in the inner most region of the (u,v) sample plane make extended structures invisible to interferometers.
  - We plan to combine GBT+WSRT data in order to address this short spacing issue.

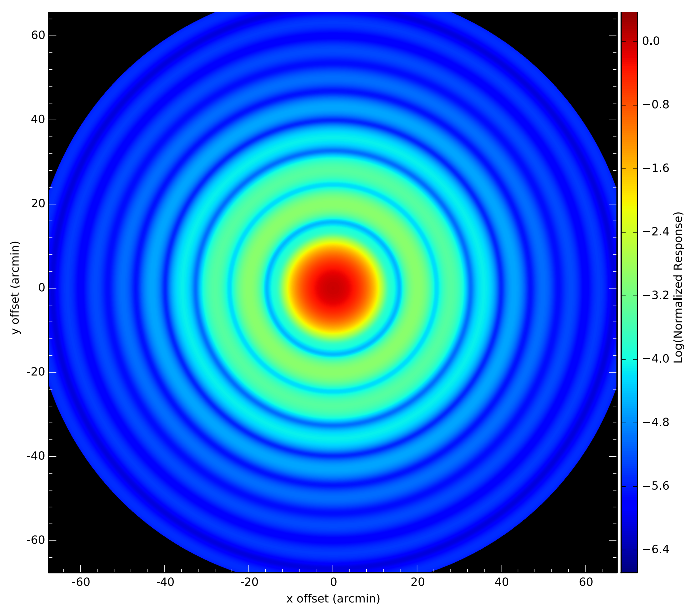
Goals for a *complete* HI census

- Build up large number statistics pertaining to galaxy properties.
  - e.g. dynamical mass, total HI mass, halo mass, SFRs, etc…
- Must have single dish observations for info at ALL angular scales
- Look for signatures of cold mode accretion
- Attempt to discern cold mode accretion from tidal interactions. May be possible by studying turbulence in extraplanar gas

Convolved WSRT Maps

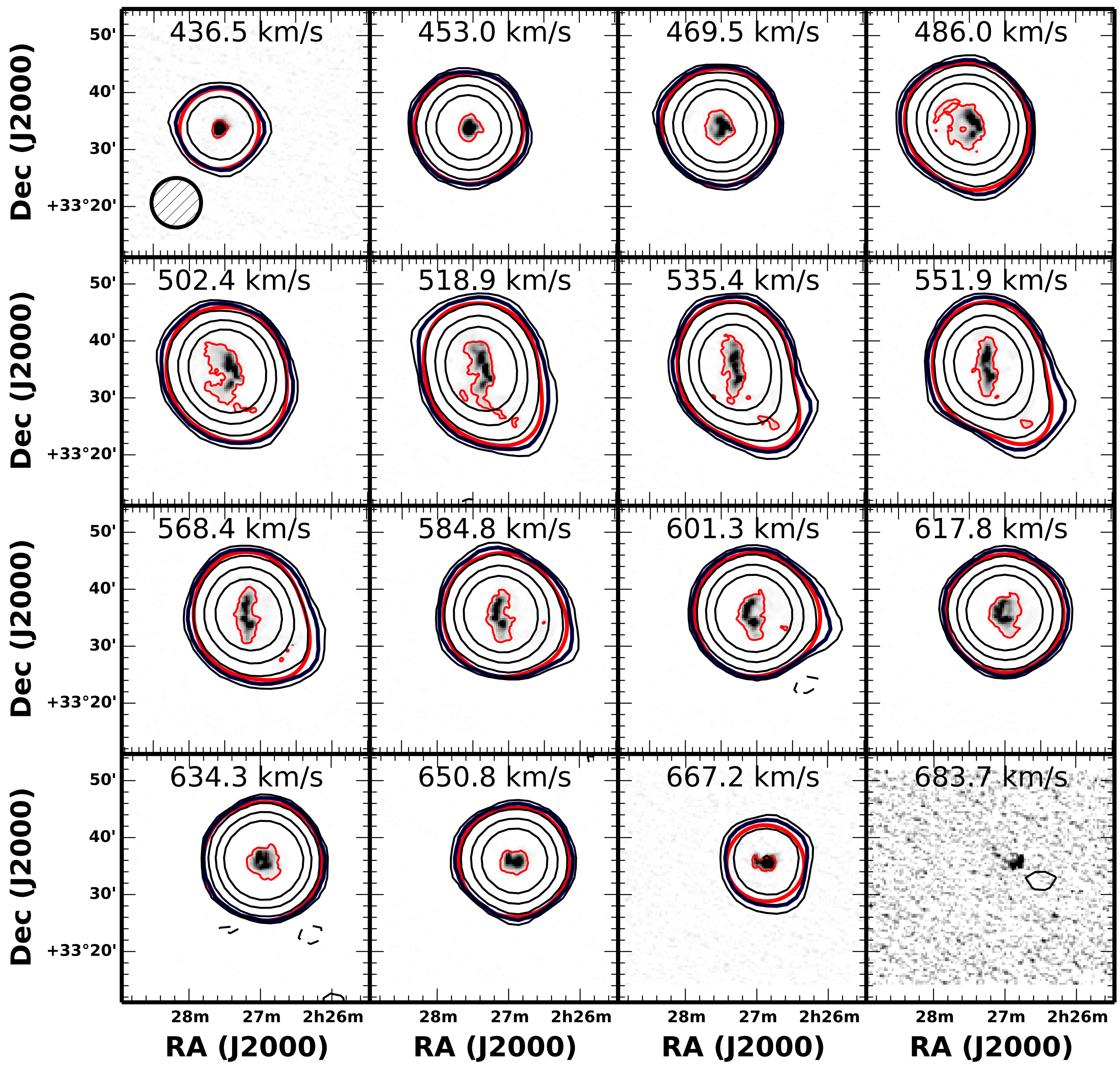
- For convolving the WSRT data to GBT resolution, conventional analysis assumes a Gaussian beam. This does not take "stray" radiation coming into the near sidelobes.
- We construct a model GBT beam map using a theoretical calculation of the GBT beam from Srikanth (1993).





Channel Maps of NGC925

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

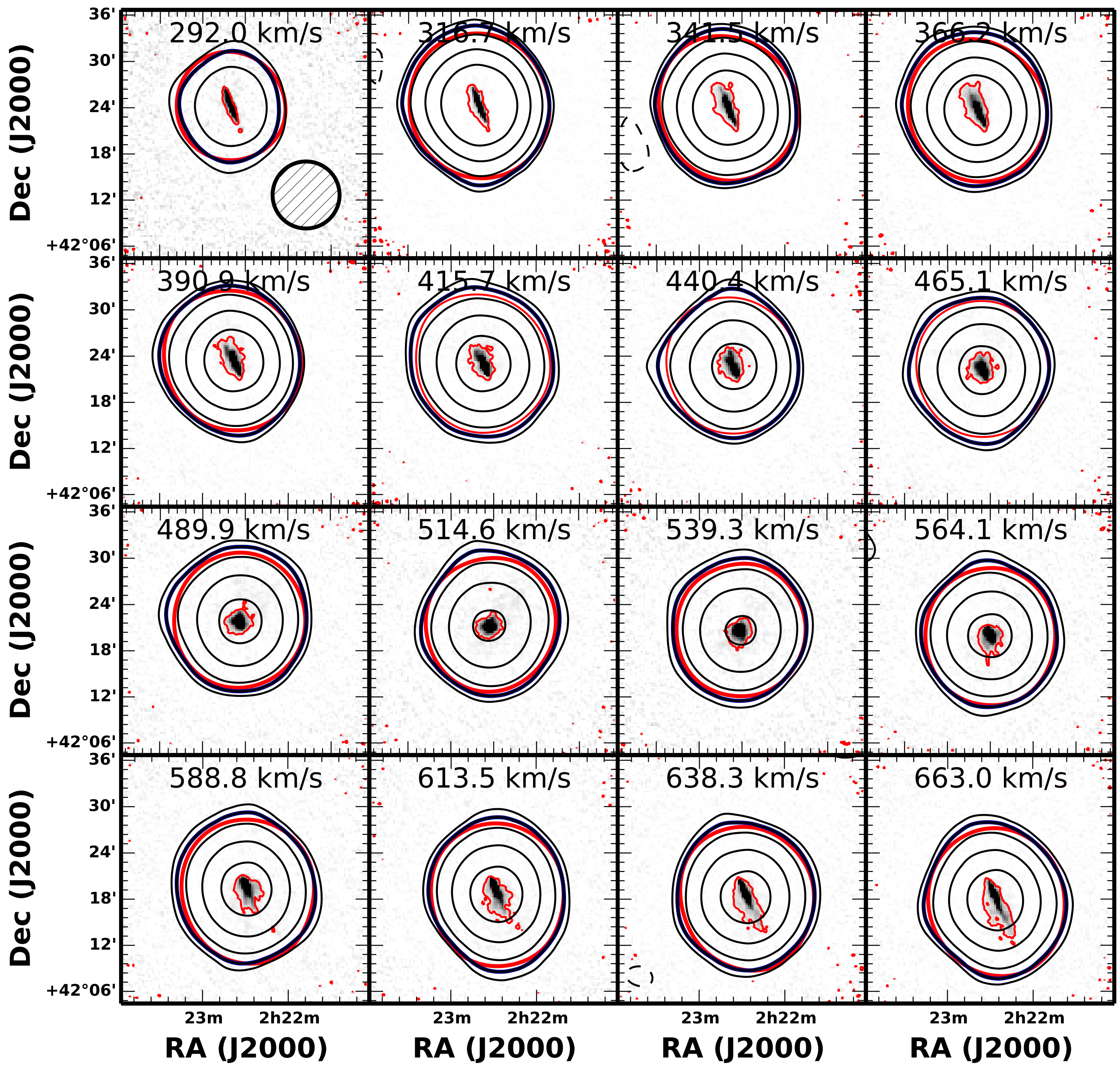


- The thick black contour in GBT map is generally more extended than its WSRT counterpart.
- We detect more flux overall in the GBT maps out to larger extents.

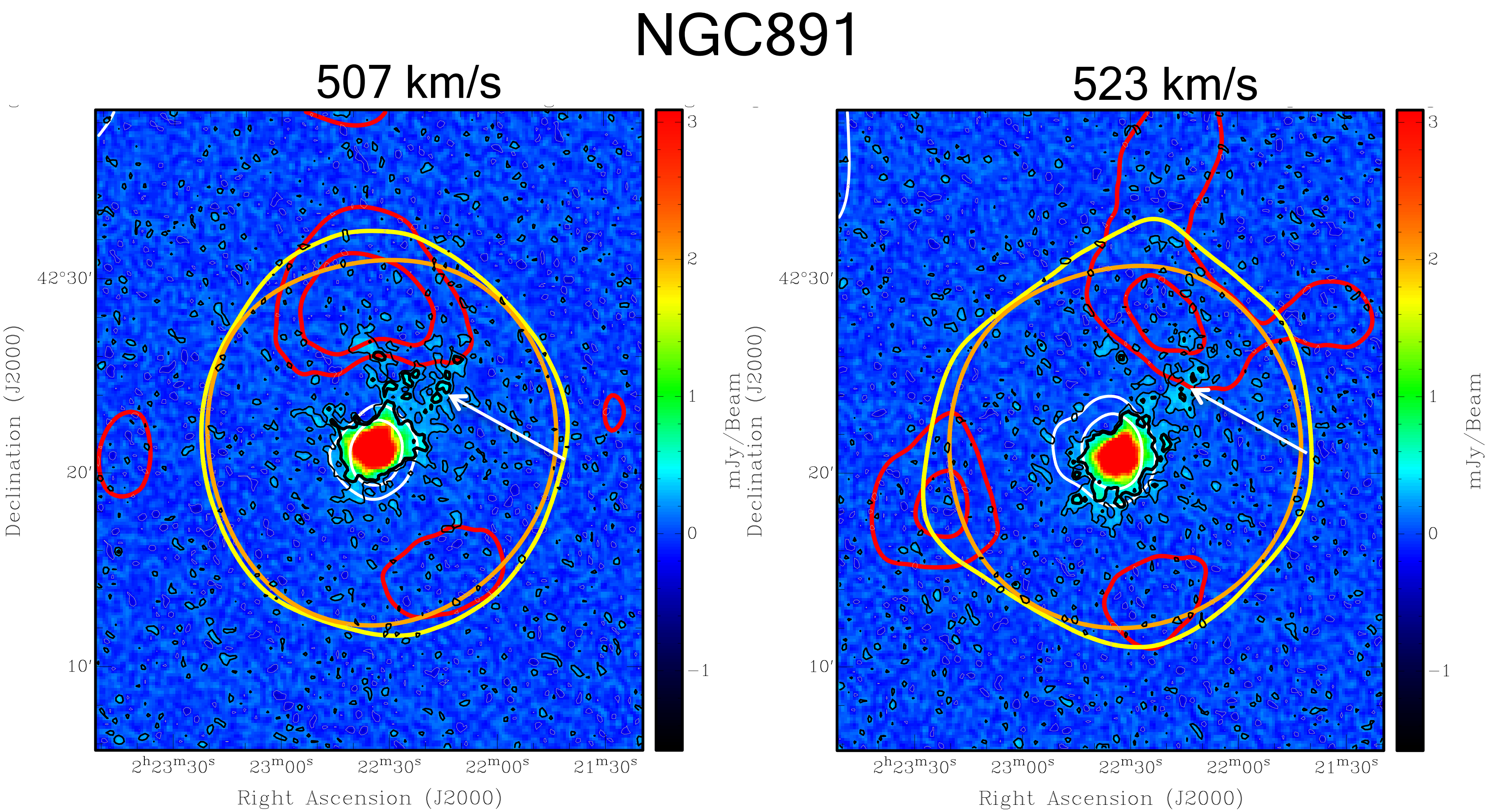
Channel Maps of NGC891

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 is detecting low column density HI out to larger extents.



What can the residual maps show us?



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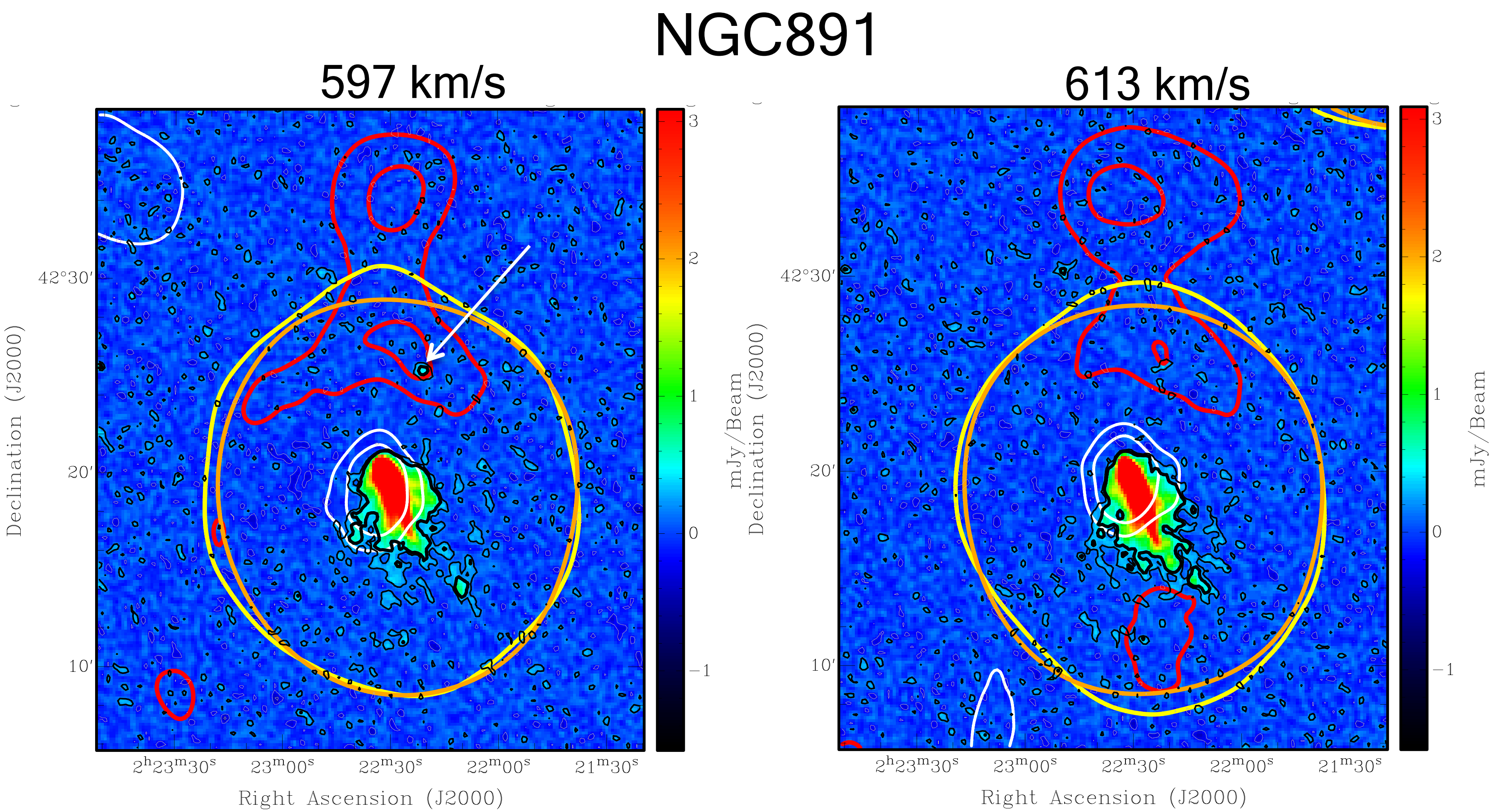
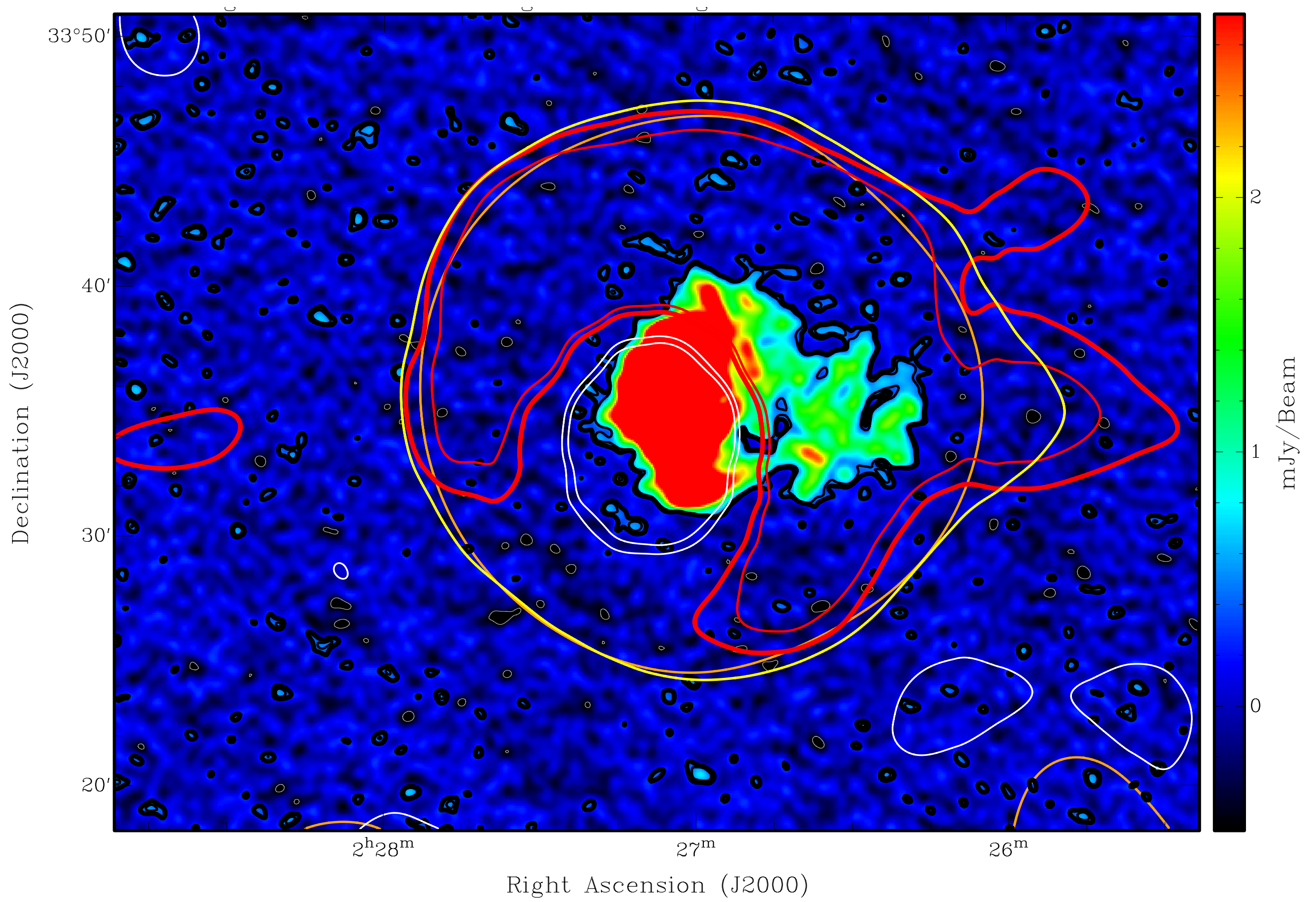
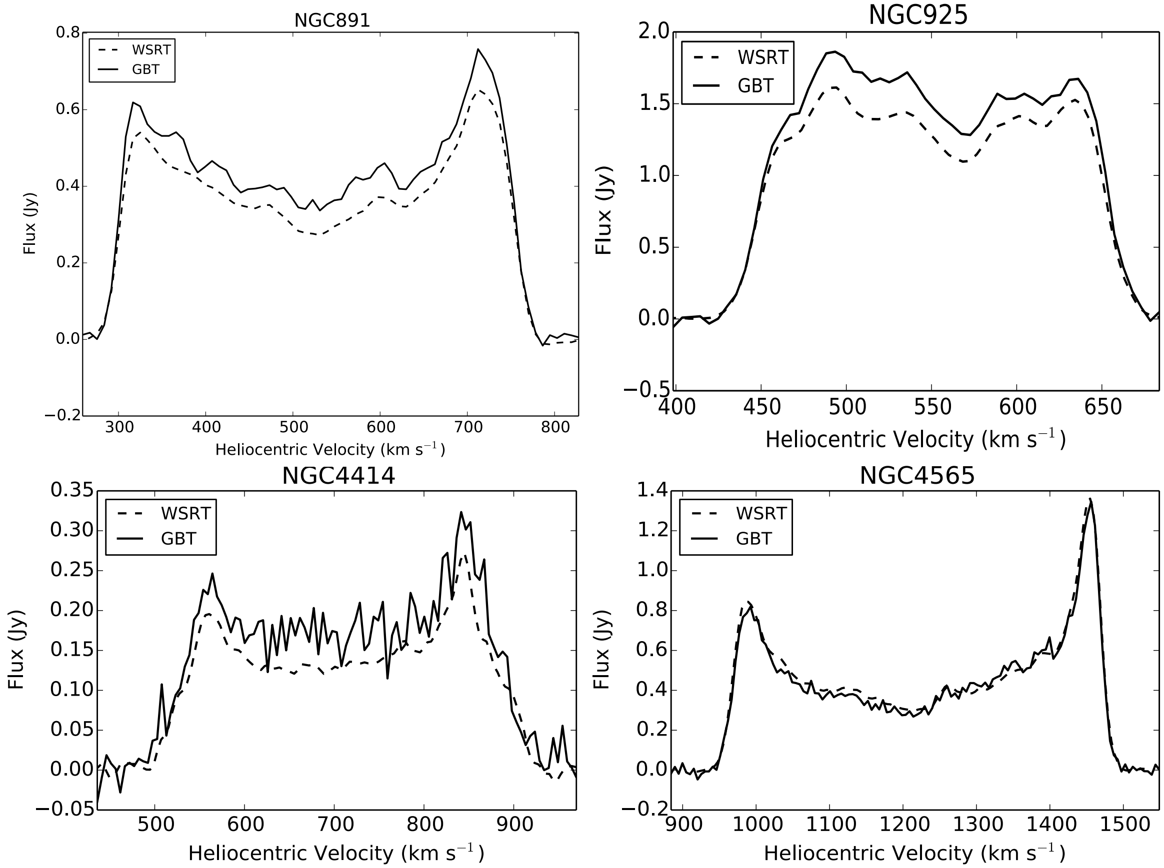


NGC925


33°50′
40′
30′
20′
Declination (J2000)
2h28m
27m
26m
Right Ascension (J2000)
2
1
0
mJy/Beam

Results

- 2σ and 3σ detections in the residual maps trace excess emission seen in channel maps of NGC891.
- Areal analysis of low N_{HI} pixels show GBT/WSRT area to be > 1 for all sources.
- To confirm this excess emission and study the spatial extent, we need an actual beam map of the GBT beam.



Focal L-band Array for the GBT (FLAG)

- Backend for cryogenic phased array feed (PAF)
- Tsys/η~50 K at ~1500 MHz. This will improve when dipole elements are upgraded and optimally spaced.
- 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.