# When it Rains, it Pours:

## An Abundance of New Small HI Clouds from the GALFA-HI Survey

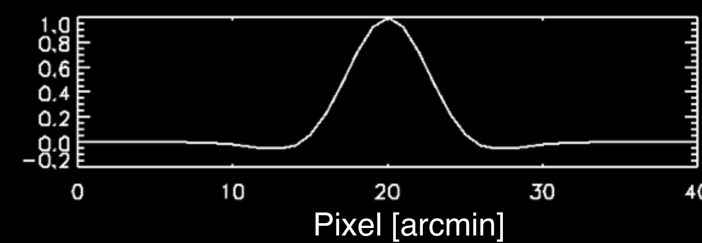
Destry R. Saul, J. E. G. Peek, J. Grcevich, M.E. Putman, et al.
Columbia University

The Galactic Arecibo L-Band Feed Array HI (GALFA-HI) Survey has allowed us to discover a wealth of small HI clouds in the vicinity of the Galaxy. Using a custom source-finding algorithm, we have identified approximately 2000 clouds smaller than 20 arcminutes and isolated from other gas with absolute velocities less than 700 km/s. We separate the catalog into five populations that correspond to different Galactic environments: 1 - high velocity clouds, 2 - galaxy candidates, 3 - cold low-velocity clouds, 4 - warm low-velocity clouds, and 5 - a low-velocity extension of a high-velocity complex.

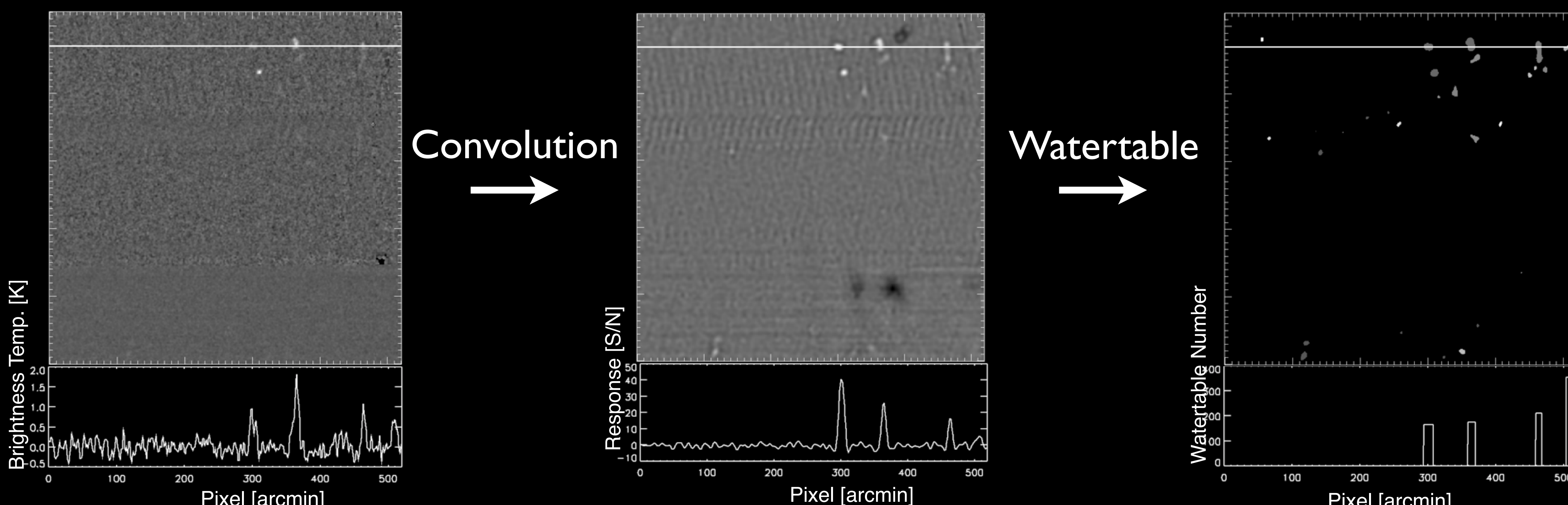
With sizes on the parsec scale, column densities of $\sim 10^{19}\mathrm{cm}^{-2}$, and masses of 1-100 solar masses, these clouds are not observable in other galaxies, giving us a distinct view of accretion at small scales.

# Truffles: A custom source-finding algorithm

When completed, the GALFA-HI Survey will cover the 13,000 square degrees (Dec = -1° to 38°) observable with the Arecibo Telescope at ~4' and 0.18 km/s resolution (Peek et al 2011). To search the first data release for neutral hydrogen clouds down to the resolution and sensitivity limits, we designed a custom source-finding algorithm utilizing machine vision ideas to get a computer to 'see' the structures we are interested in.

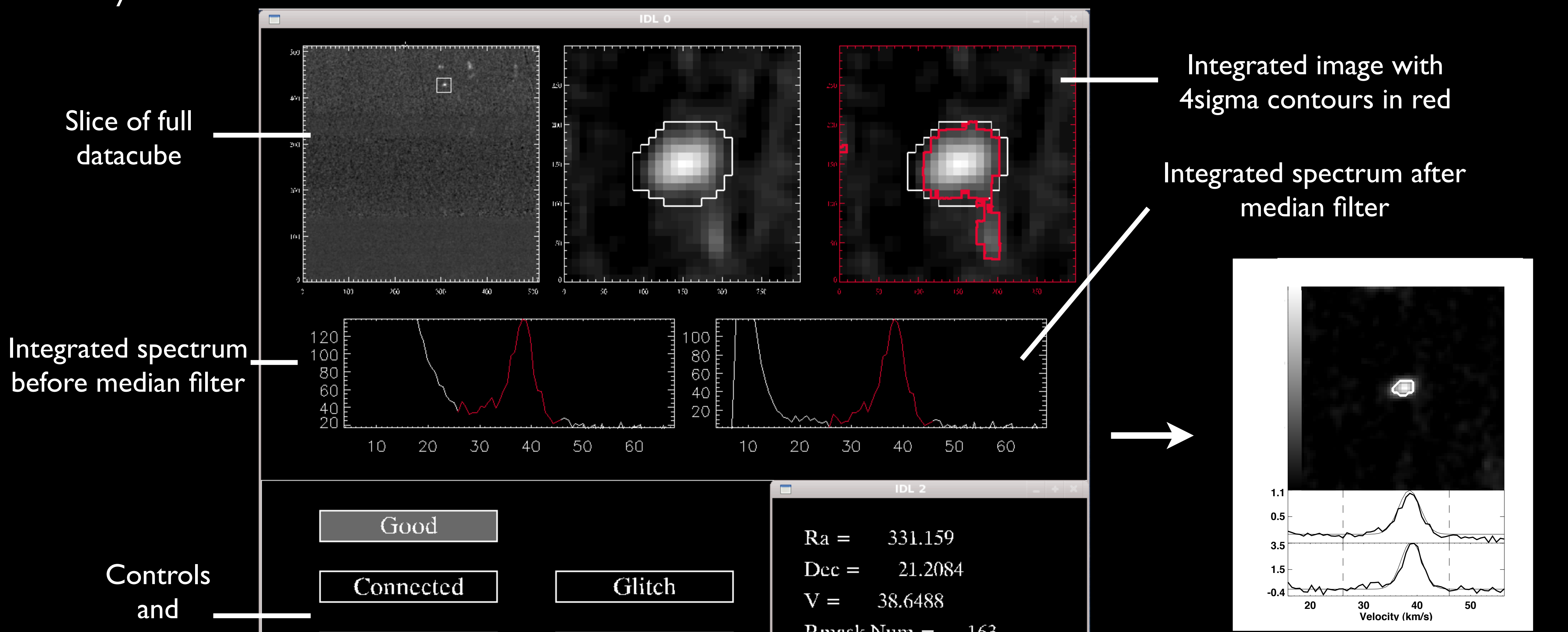



First, we use a one square degree median filter to subtract off large smooth structures. Then, the data are convolved with a three-dimensional kernel (pictured above in 1D). The kernel size is tuned to be sensitive to a small range of sizes. Clouds that are well-matched to the kernel shape are accentuated while noise is smoothed down. The resulting convolved datacubes are analyzed using common watertable source-finding. The peak is identified, and an 'island' is grown around the peak down to a 'watertable' at the noise level. This is repeated until all the islands above a threshold are found. To search for clouds ~4-20' and 2-25 km/s, we used four kernels: 7' & 5km/s, 7' & 15km/s, 18' & 5 km/s, 18' & 15km/s. We found the response dropped by less than 15% for test clouds with sizes between the kernel sizes. We merged the island information for each kernel to identify clouds candidates.

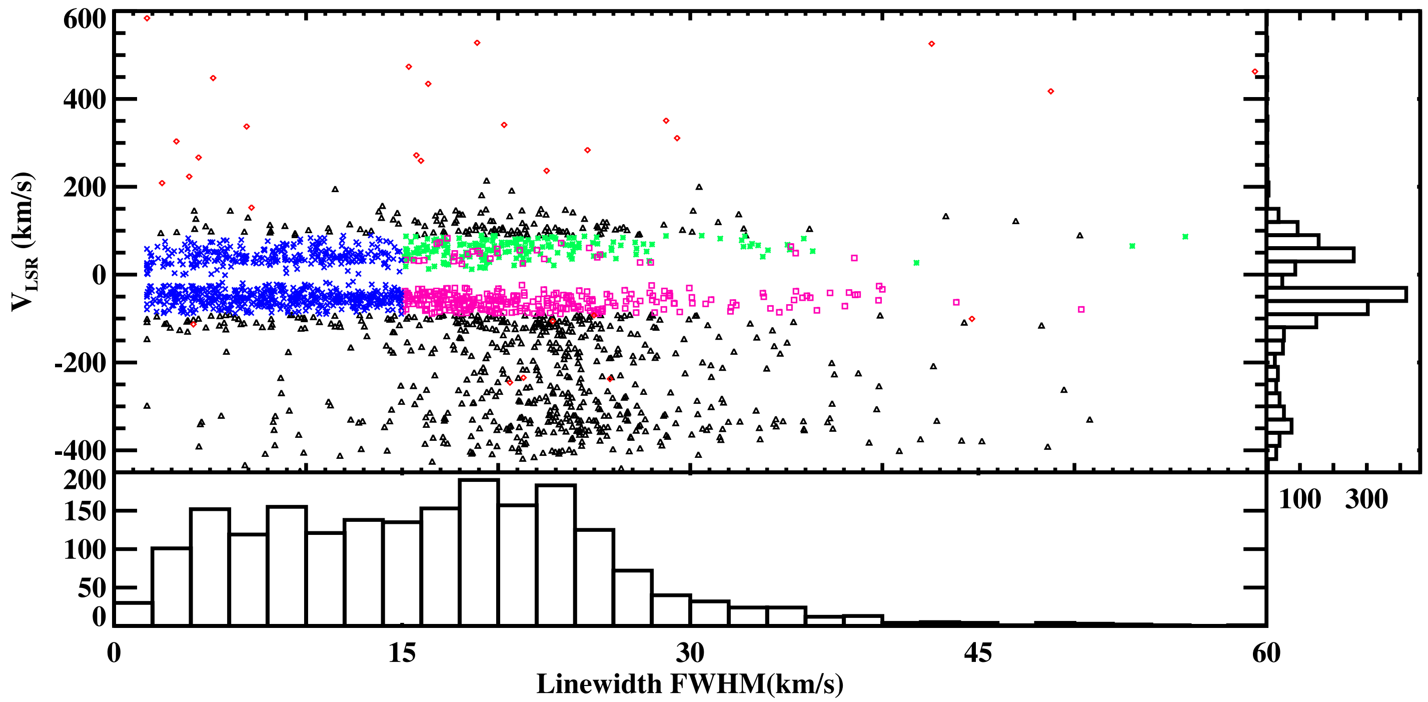


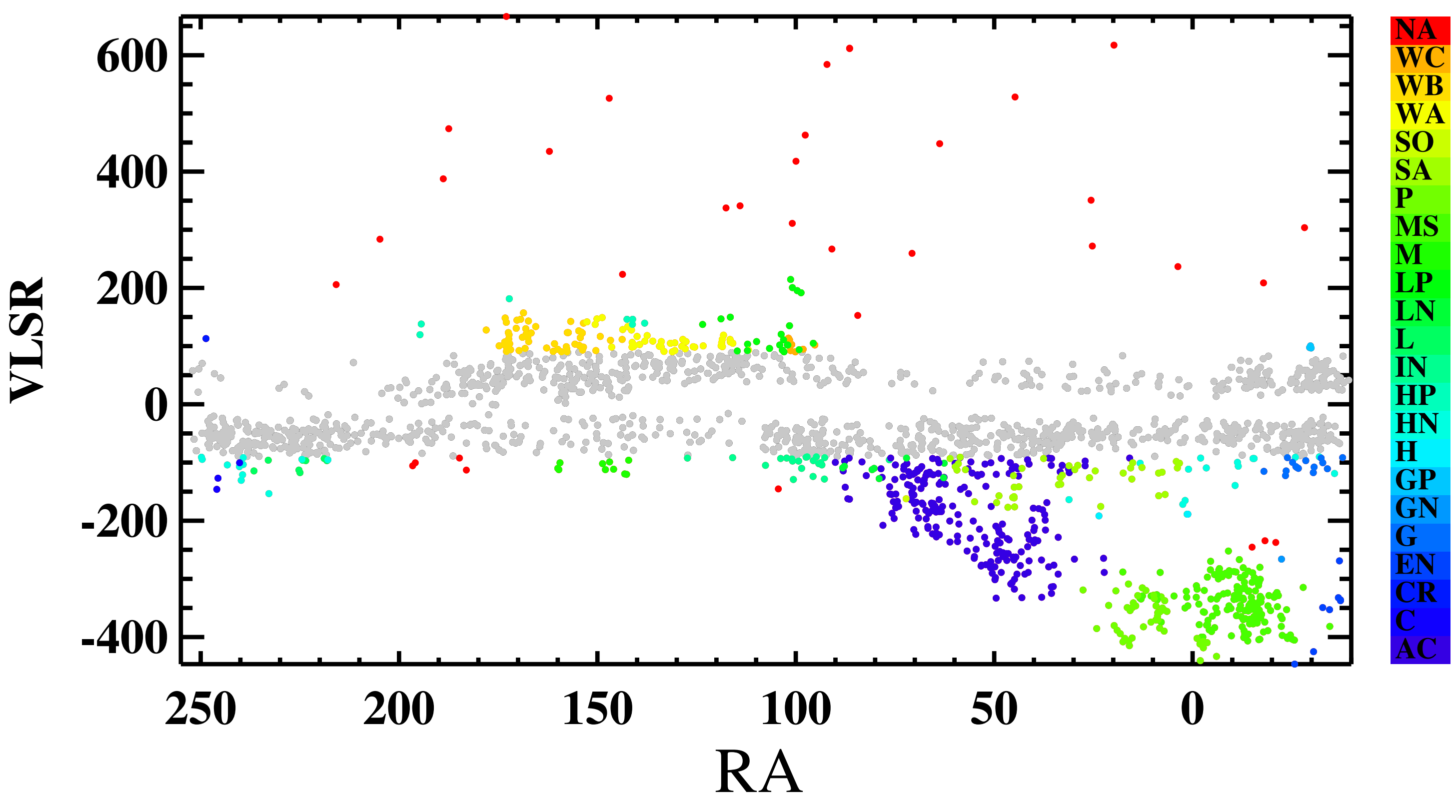
# BlobZoo: Efficiently Evaluating Cloud Fidelity

While Truffles was effective at identifying significant structures, it included many structures we were not interested in, i.e. peninsulas, filaments, and noise spikes. To assure the quality of our catalog was high, we required that each cloud candidate was inspected by at least three authors, with a majority in agreement. An inherent difficulty with examining the cloud candidates Truffles identified is their three dimensionality and the large number of clouds to examine (~10,000 candidates). We built an interface inspired by GalaxyZoo to display as much information on each cloud as possible, and record the viewer's decision. The screenshot below shows one of the clouds from the previous page. Besides the images and spectra displayed below, the user can scan through the datacube to see the three dimensional structure of the cloud. This was important to determine whether or not a cloud was connected to a larger structure, or truly isolated. The individual spectrum through any point could also be inspected easily.




This cloud as it will appear in the catalog, with integrated image, average spectrum and the spectrum through the peak.




We identify five populations of clouds. They are most easily seen in the linewidth vs. velocity plot on the upper left.

## 1. High Velocity Clouds (Black Triangles)

For clouds with LSR velocities above 90km/s, we find that the majority are near known HVC complexes using the method from Peek et al. 2007. We used the Wakker91 catalog of HVCs. The plot on the lower left shows this result with each color representing a different HVC complex.

## 2. Galaxy Candidates (Red Hearts)

A small number of high velocity clouds were not associated with known HVC complexes. The majority of these have positive LSR velocities, and small spatial sizes, evidence that they may be undiscovered gas-rich galaxies.

## 3. Cold Low-Velocity Clouds (Blue Xs)

We separate the clouds with LSR velocities less than 90km/s into cold and warm populations. We use a FWHM linewidth of 15 km/s, which for purely thermal broadening corresponds to ~5000K. The upper left plot, and the plot on the next slide show how these clouds are relatively evenly distributed in position and velocity

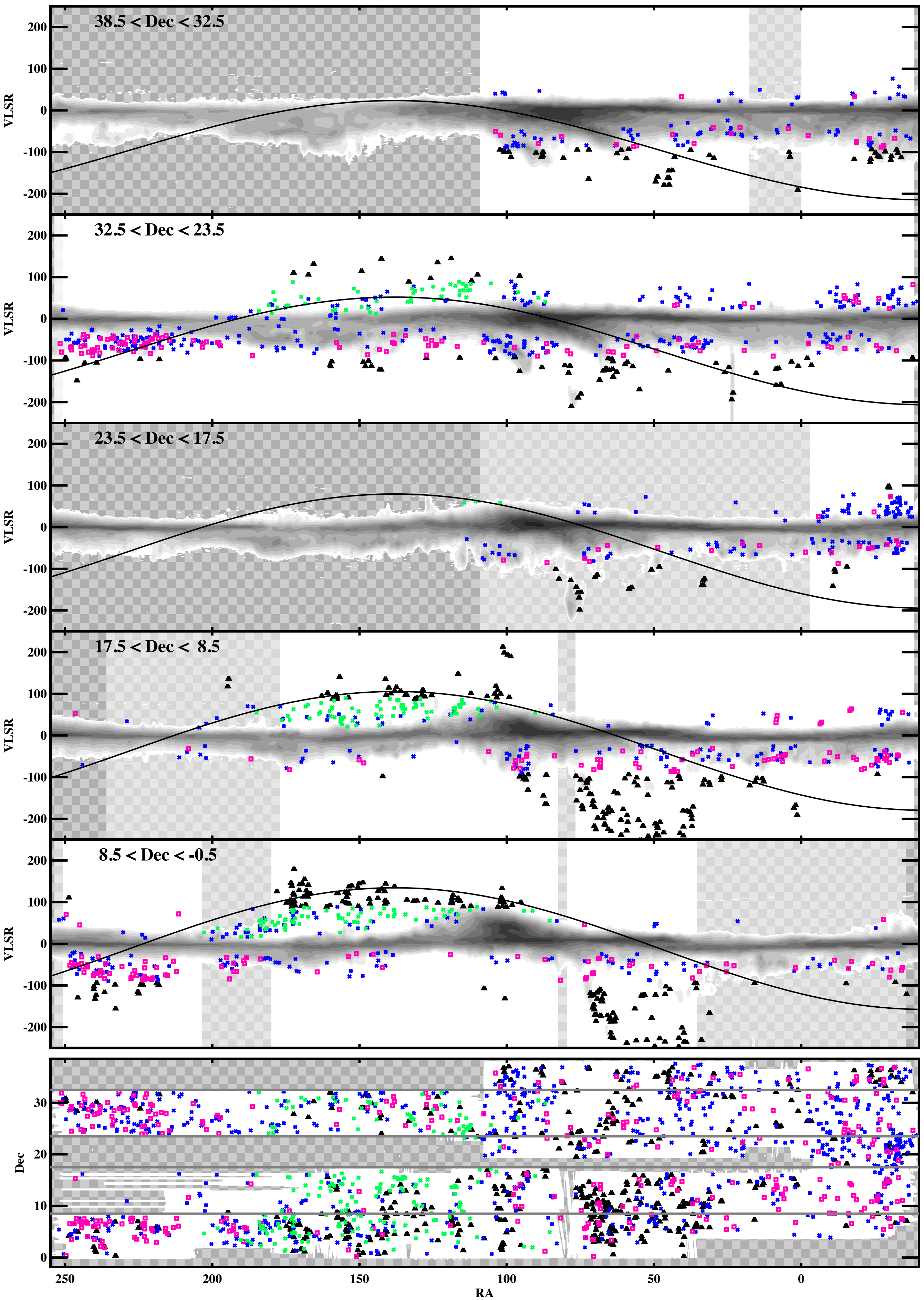
## 4. Low-Velocity High Velocity Clouds (Green Xs)

There is an interesting group of clouds with linewidths > 15km/s and positive LSR velocities that are grouped in RA between 90 and 200 degrees (See next slide). This region is where it is possible for a cloud that is not co-rotating to appear at positive LSR velocities due to our rotation in the Galaxy. We note that these clouds are near the WA, WB, and LP HVC complexes and propose that these low-velocity clouds are infalling halo clouds that are not rotating with the Galactic disc.

## 5. Warm Low-Velocity Clouds (Pink Squares)

Unlike the cold clouds, the warm clouds are not evenly distributed in velocity. After extracting the warm clouds discussed above, we find that they are predominately at negative LSR velocities, and mostly evenly distributed in position.

| Population | Number | $\overline{V_{LSR}}$ (km s$^{-1}$) | $\delta V_{LSR}$ | $\overline{\Delta V}$ (km s$^{-1}$) | $\delta\Delta V$ | $\overline{N_{HI}}$ (x10$^{18}$cm$^{-2}$) | $\delta N_{HI}$ | $\overline{Size}$ (pc×d[kpc]) | $\delta$Size | $\overline{Mass}$ ($M_\odot$×d[kpc]$^2$) | $\delta$Mass |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HVCs | 703 | -163 | 167 | 22 | 9 | 13 | 11 | 1.4 | 0.4 | 2.7 | 3.1 |
| Galaxy Candidates | 35 | 264 | 269 | 25 | 21 | 20 | 25 | 0.78 | 0.2 | 0.9 | 1.0 |
| Cold LVCs | 754 | -18 | 50 | 8 | 4 | 8 | 8 | 1.1 | 0.3 | 0.8 | 1.0 |
| Warm LVCs | 321 | -50 | 35 | 22 | 6 | 12 | 10 | 1.3 | 0.5 | 2.3 | 2.1 |
| Low Velocity Halo Clouds | 196 | 58 | 19 | 22 | 6 | 11 | 7 | 1.3 | 0.4 | 2.0 | 2.7 |




# This plot displays the position and velocity information for the clouds with absolute LSR velocities < 250 km/s

The colors are the same as the upper plot in the previous slide: Black - HVCs, Blue - Cold LVCs, Pink - Warm HVCs, Green - Low Velocity Halo Clouds. The Galaxy candidates are not included.

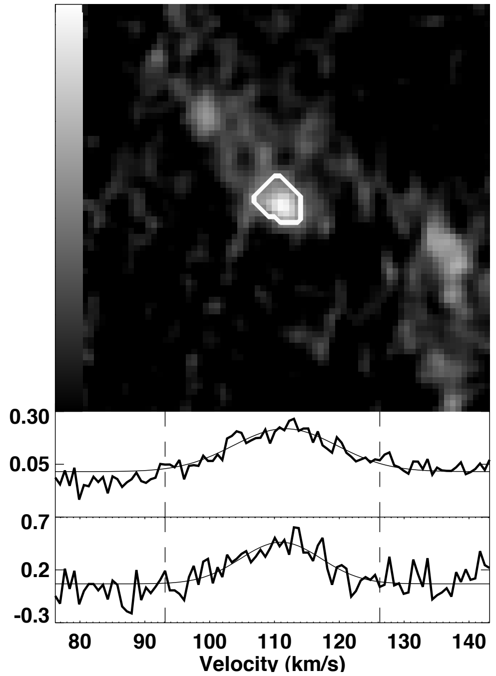
The bottom pane displays position in Ra/Dec with the sky coverage of the GALFA-HI first data release. The dark hashed areas were not included. The horizontal lines indicate the declination ranges used in the upper panes.

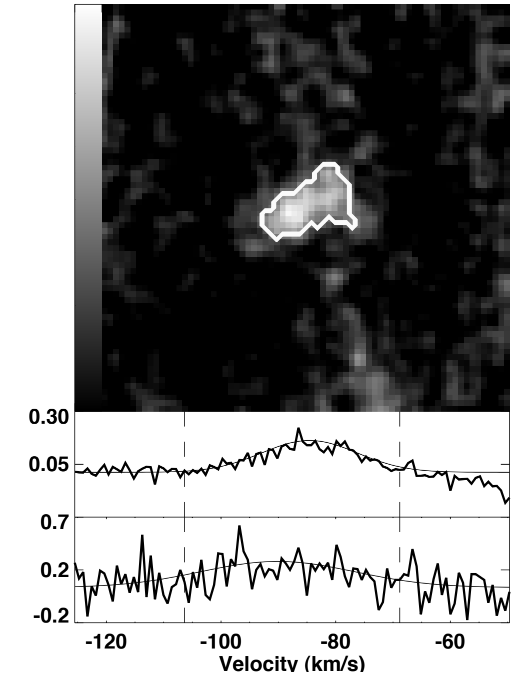
The upper five panes have the LAB survey (Kalberla et al 2005) plotted in greyscale integrated over the declination ranges stated. The hashed areas indicate the amount of coverage in that region, darker hash for fewer data.

The thin curved line shows the LSR velocities that correspond to zero in the Galactic Standard of Rest (GSR) frame. Along that line, a cloud could be unaware of Galactic rotation.

Notice that the green and black points are at positive velocities only in the region where positive LSR velocities can be negative GSR velocities. Also, note the lack of warm LVCs (pink) at positive LSR velocities.

There is some increase in density in LVCs at RA =250 and 330, where the survey approaches the inner Galactic plane. This could be consistent with these clouds being in the lower halo.



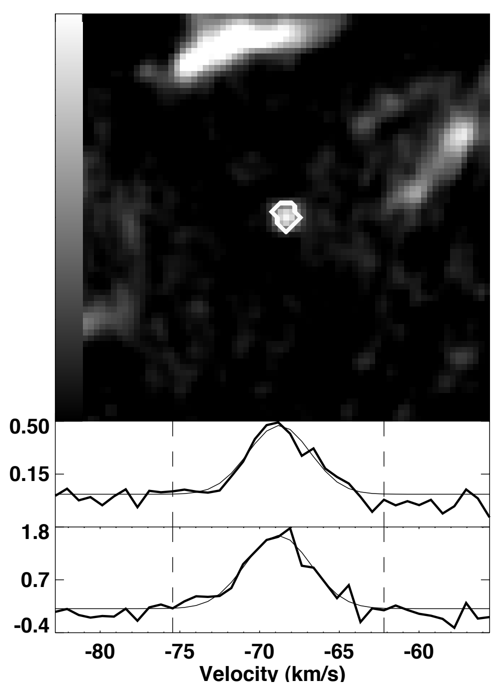

# Conclusions

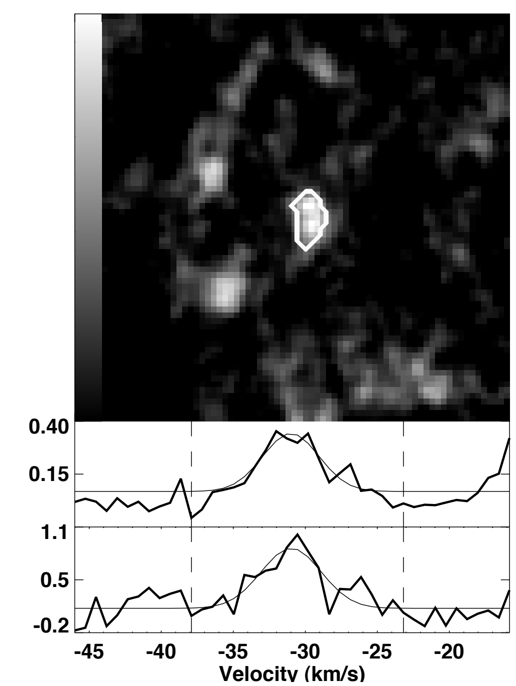
Using a custom source-finding algorithm we have identified five populations of HI clouds.

We find the majority of the high velocity clouds are associated with previously known HVC complexes. We do not see an evenly distributed population of isolated clouds at high velocities.

We find a population of cold clouds at low positive and negative velocities. The low velocities indicate that these clouds are associated with the Galactic disc.

The warm low-velocity clouds are all observed to be infalling, with the exception of a number of clouds at positive LSR velocities located where they have mostly negative velocities in the GSR frame. The positive LSR velocity clouds are also positioned near several known positive velocity HVC complexes.

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