Detecting the Warm Neutral Medium in Absorption with 21-SPONGE

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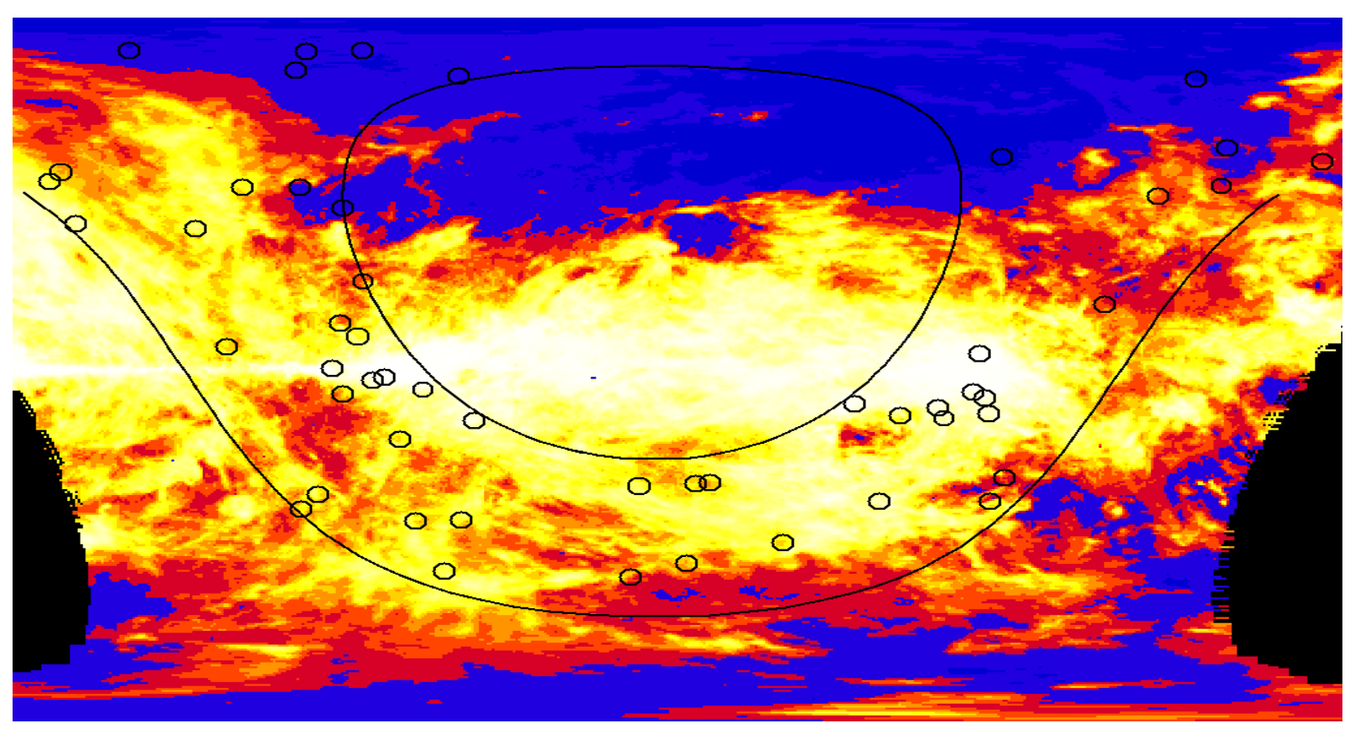
Scientific Motivation:

Although properties of the cold neutral medium (CNM) have been measured extensively in studies of the neutral interstellar medium (ISM), very few direct measurements of its counterpart, the warm neutral medium (WNM), exist to date. The optical depth of the WNM is very low ($<10^{-3}$) and therefore it is difficult to detect in the presence of strongly absorbing, cold gas. Given the expanded capabilities of the Karl G. Jansky Very Large Array (VLA), we can reach sensitivities in optical depth of $<5\times10^{-4}$, allowing us to directly detect absorption signatures corresponding to gas in the full theoretical temperature regime of the WNM (Ts~5,000-10,000K). Our project, **21-SPONGE** (*21-cm Spectral Line Observations of Neutral Gas with the EVLA*) will survey 58 high-latitude, strong continuum sources to detect WNM directly in absorption, and will ultimately determine the temperature and column density distribution of this elusive phase of the ISM. We present an analysis of the first 20 sources.

The Karl G. Jansky Very Large Array (VLA) science.nrao.edu



Galactic HI map with the Arecibo field of view and 21-SPONGE sources.

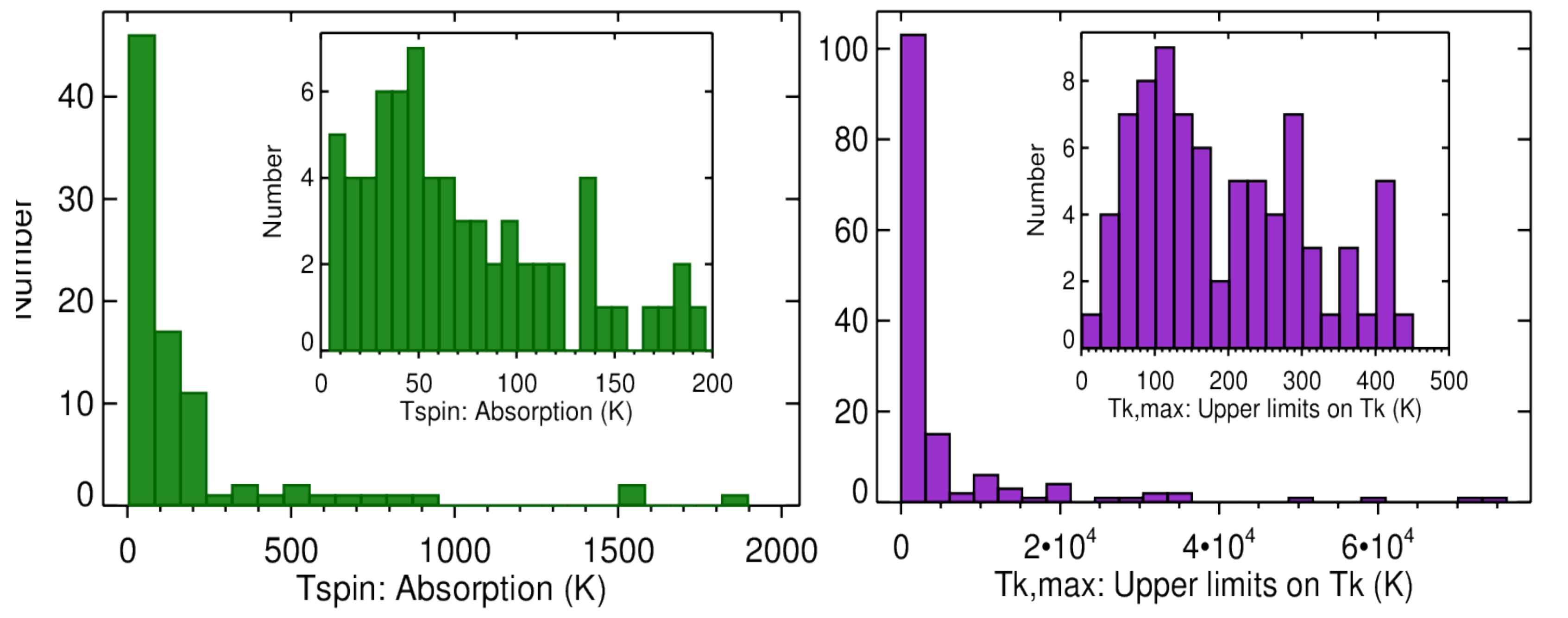


Figure 1: Histograms of derived temperatures for the first completed 20 sources. **Left**: spin temperatures derived from Gaussian decomposition of VLA absorption profiles, solved in comparison with Arecibo emission profiles. **Right**: maximum kinetic temperatures derived for both absorption and emission components.

Current Temperature Results

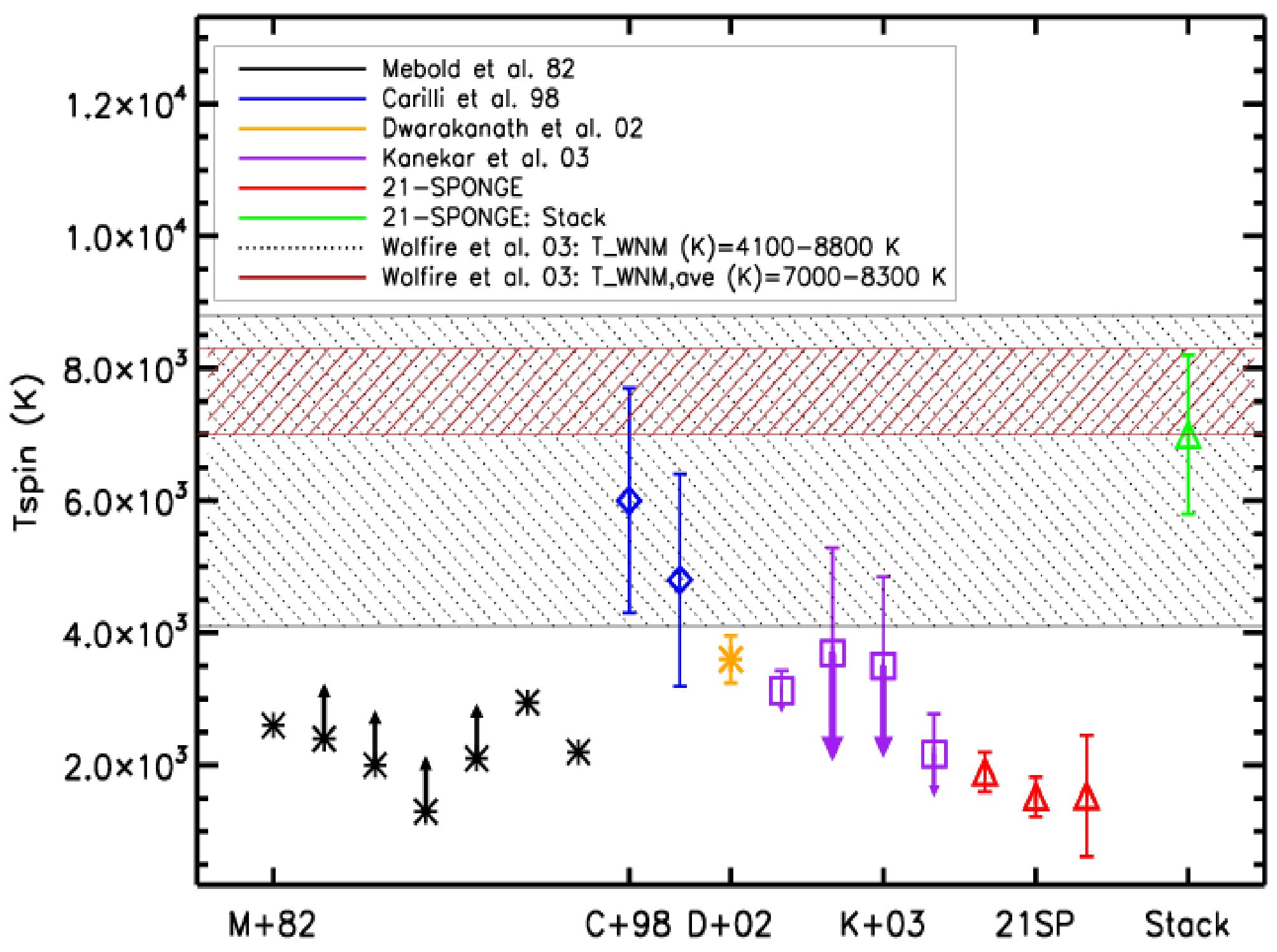
After obtaining matching emission spectra from the GALFA-HI survey at Arecibo or the Millennium Survey by Heiles & Troland (2003; HT03), we fit each spectrum with multiple Gaussian components and solve radiative transfer equations by the method of HT03. We have fully processed data for 20 sources (with 1 non-detection), and we calculate the maximum kinetic temperatures (Tk) of all WNM and CNM components and spin temperatures (Ts) of all absorption components. See Figure 1.

	21-SP	HT03
Ts<100 K:	58%	77%
100<Ts<1000 K:	38%	23%
Ts>1000 K:	4%	0%

	21-SP	HT03
Tk<500 K:	14%	10%
500<Tk<5000 K:	45%	39%
Tk>5000 K:	41%	51%

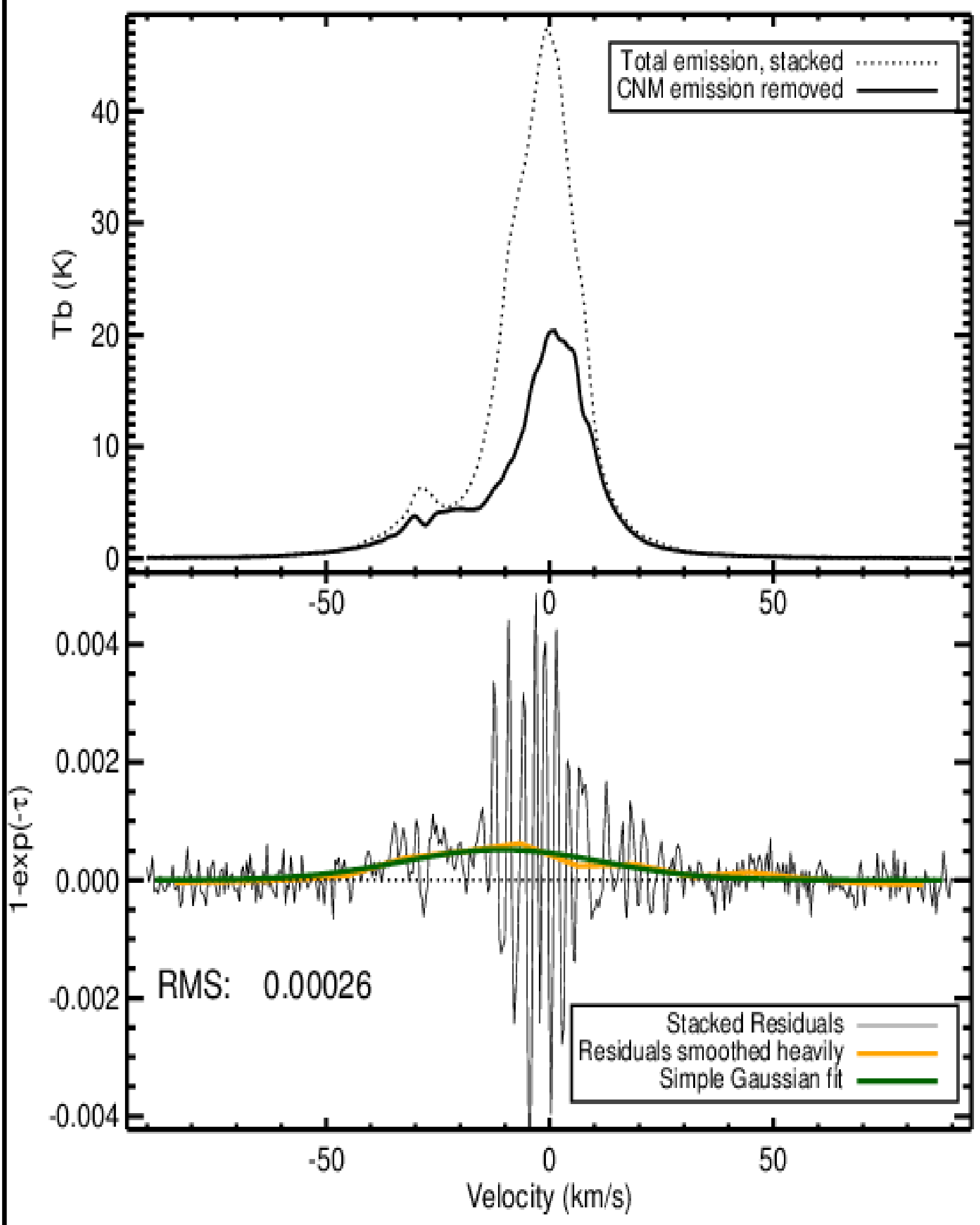
Theoretical models predict that the WNM should have Tk~5000-8000 K (Wolfire et al. 2003). Although Tk should roughly equal Ts for the CNM, Ts<Tk for the WNM due to contributions from non-collisional processes, e.g. turbulence (Liszt 2001). But despite our high sensitivity (median Δτ_rms =0.0007 per 1km/s channel), we do not see many features with Ts>1000 K (max Ts=1830 K). Stacking the residuals (see right) pulls out an apparently warmer feature, however we expected more individual detections. This could imply that the fraction of thermally unstable gas (500<Ts<5000K) is smaller than predicted.

Figure 2: (left) Comparison of previous WNM detections in absorption. The K+03 detections are upper limits from line widths alone. The temperature associated with our stacked component falls within the predicted temperature range for the WNM by Wolfire et al. (2003).



Increasing Sensitivity: Stacking

To further increase sensitivity to weak absorption features, we stacked the residual profiles from our fitting analysis. We first removed all fitted Gaussian components from the absorption profiles and then removed their corresponding emission features. We then centered each profile by the velocity of maximum residual emission, and computed a weighted average of all profiles.



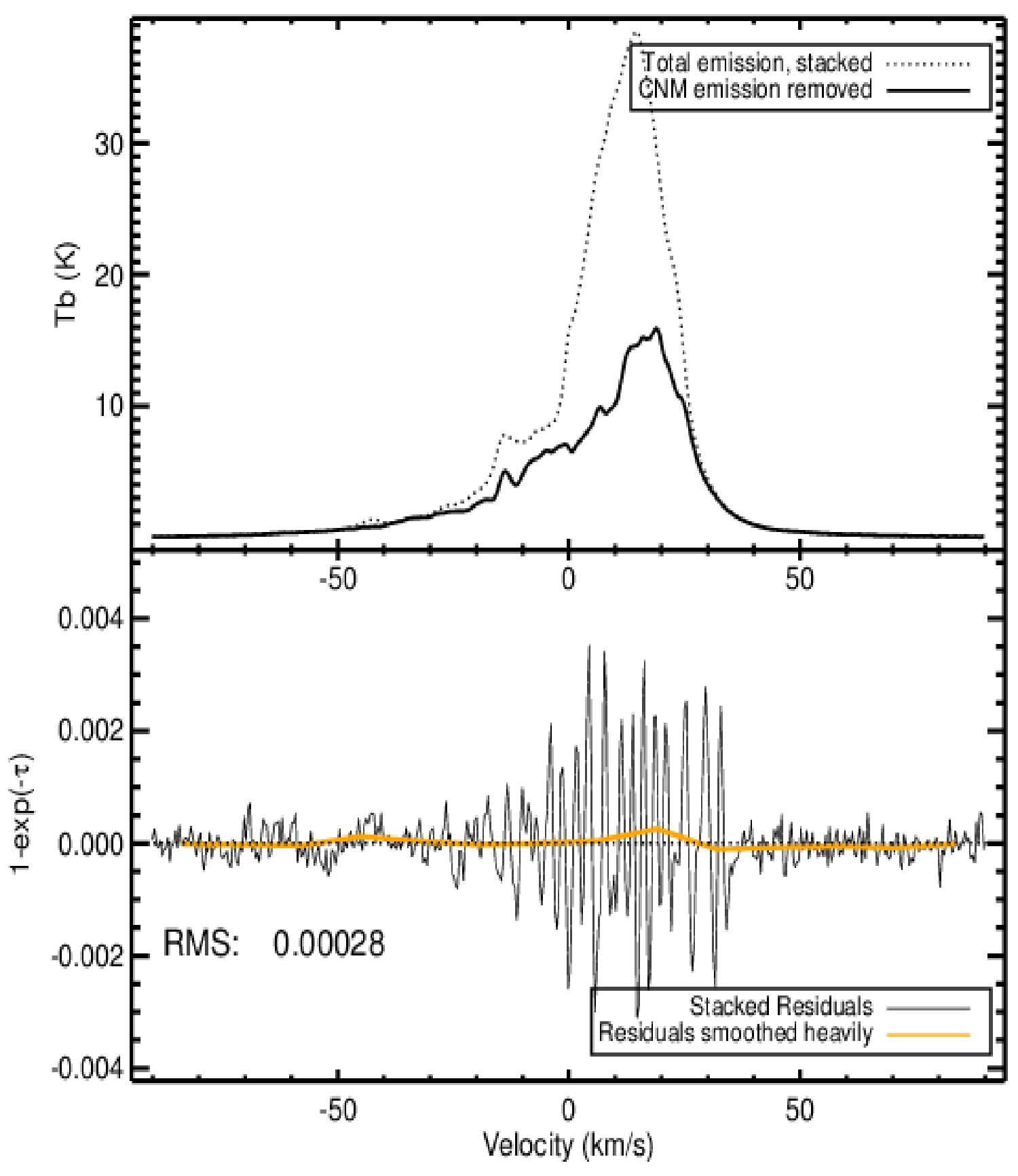


Figure 4: (above,right) Stacked residuals profiles after random velocity shifting and random residual flipping, demonstrating that the feature of interest disappears.

Figure 3: (above,left) Stacked residual emission and absorption profiles following Gaussian decomposition and centering around the velocity of maximum emission. Sharp, spiky residuals around 0 km/s indicate complex velocity structure missed by Gaussian fitting.

Δv	~50 km/s
Tk,max	~60,000 K
$Ts\sim Tb/(1-e^{-\tau})$	~7000 K
N_HI	$\sim2\times10^{20}$ cm^{-2}
tau_peak	6e-4 +/- 1e-4
Δτ rms	2.6e-4
Δτ rms (smoothed)	5.0e-5

The results above show a promising absorption feature, corresponding to emission in the same velocity range. This feature is destroyed by random shifts (Fig 4). At right, we present estimated parameters for the feature of interest. Assuming $T_B=T_S(1-e^{-\tau})$, the spin temperature is T_S~7000 K, which falls within the expected regime for the WNM. Future work will incorporate the effects of stray radiation and CNM vs. WNM biases in fitting analysis to strengthen these conclusions.

References: Heiles, C., Troland, T. H., 2003, ApJ, v.586, p. 1067-1093, Liszt, H., 2001, A&A, 371, 698, McKee, C.F., Ostriker, J.P., 1977, ApJ, v.218, p. 18-169, Wolfire, M.G. et al., 2003, Apj, 587, 278.
(Murray et al. 2013, in prep).

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