How "Warm" is the Warm Neutral Medium?

Claire E. Murray[1], Snezana Stanimirovic[1], Robert R. Lindner[1], W. M. Goss[2], John Dickey[3], Carl Heiles[4], Brian Babler[1], Patrick Hennebelle[5]

contact: cmurray@astro.wisc.edu

1: University of Wisconsin -Madison, USA, 2: NRAO, USA, 3: UTas, Australia, 4: UC-Berkeley, USA, 5: CEA/IRFU, France

Abstract

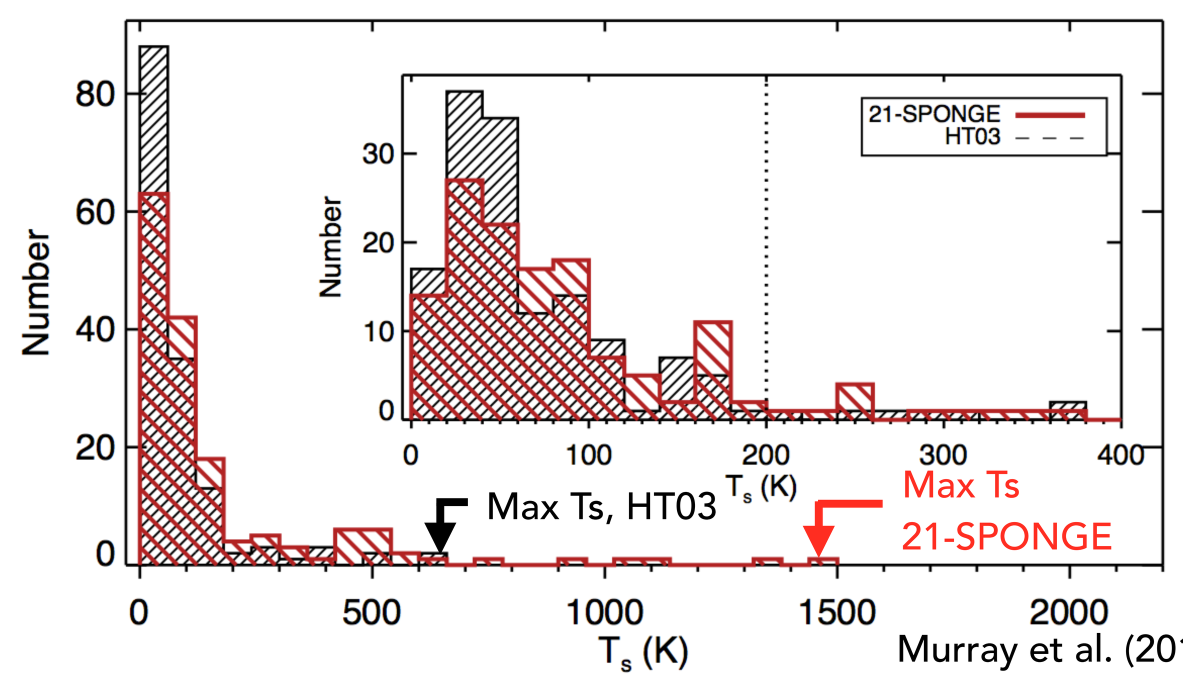
To understand how cold star-forming material (H2) forms from diffuse HI, we must constrain the properties of HI in all phases. We are conducting a large HI absorption survey, **21-SPONGE** (21-cm Spectral Line Observations of Neutral Gas with the VLA), comprised of 58 high-lbl sight lines (31 complete) with RMS optical depth noise < 10^{-3} per 0.4 km/s channel and HI emission from the Arecibo Observatory. The key questions we aim to answer are:

- *What is the temperature of the WNM?* : We measure Ts=7200 (+1800,-1200) K via statistical stacking analysis, and do not detect WNM (Ts>2000 K) from individual absorption lines. However, CNM fractions are all <60%, implying WNM prevalence.
- *How much HI is thermally unstable?* : We find 20% absorbing HI in the unstable regime, 200<Ts<2000 K, which is crucial to constrain ISM heating/cooling models, and is much lower than previous, lower-sensitivity observational estimates.

Measuring CNM, WNM Ts

Following Heiles & Troland (2003; HT03), we fit Gaussian functions to HI emission and absorption and solve for Ts and WNM parameters of individual components:

$$T_{\rm B}(v) = T_{\rm B,WNM}(v) + T_s(1 - e^{-\tau(v)})$$



Murray et al. (2014), submitted

- No WNM gas (Ts>2000 K) from individual absorption line fits.
- Much less thermally unstable gas (~200<Ts<2000 K) than expected from previous observational studies:

Data	HI Observatories	RMS τ Noise	# of Sources	Unstable HI fraction
21SPONGE	VLA (abs), Arecibo (em)	6e-4 per 1 km/s	31	**20%**
HT03*	Arecibo (abs, em)	2e-3 per 1 km/s	79	48%
Roy et al. 2013*	WSRT, GMRT, ATCA (abs), LAB (em)	5e-4 per 1 km/s	30	28%

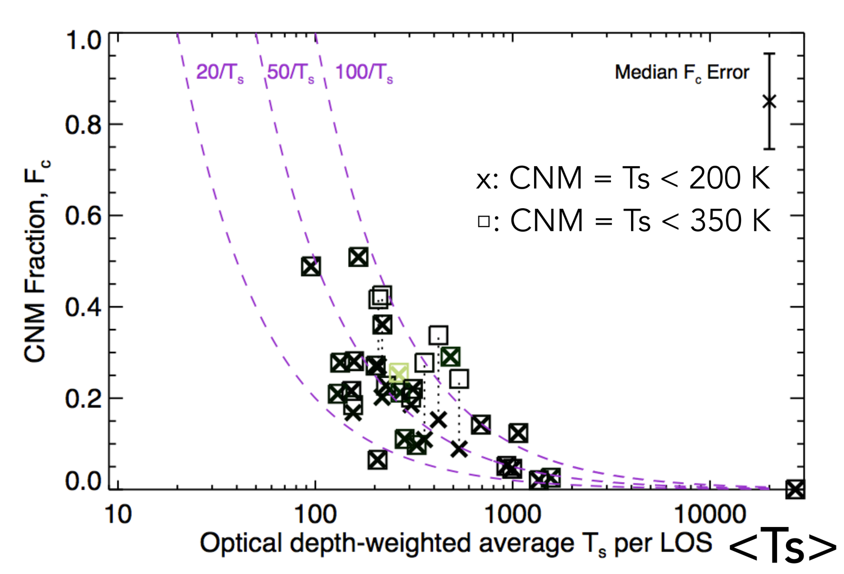
*: WNM Ts indirectly estimated from Tk, which affects fraction estimates

Trends in CNM Fraction

CNM Fraction: $F_c = \frac{\Sigma N(\text{HI, CNM})}{N(\text{HI, total})}$ = $\frac{\text{Sum of all CNM (Ts<200 K) components along the LOS}}{\text{Total LOS HI column density}}$

Average Ts per LOS (<Ts>):

- Fc follows tight trend in <Ts>, agrees with Kim et al. (2014)'s synthetic HI absorption and emission analysis of 3D HD multiphase ISM simulation.



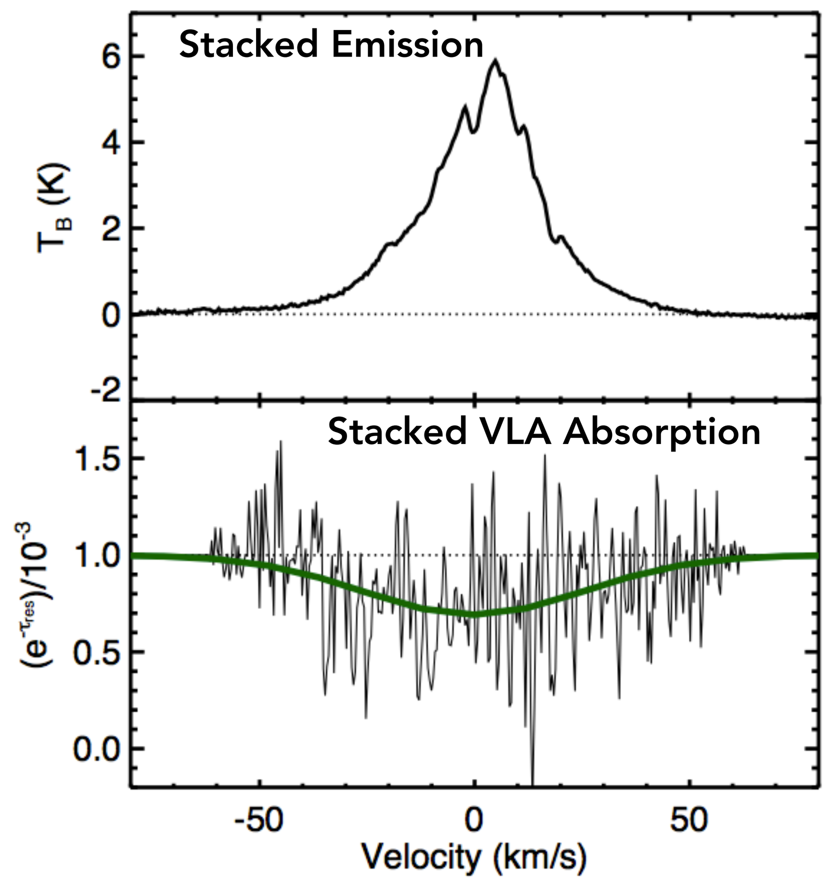
Environment:

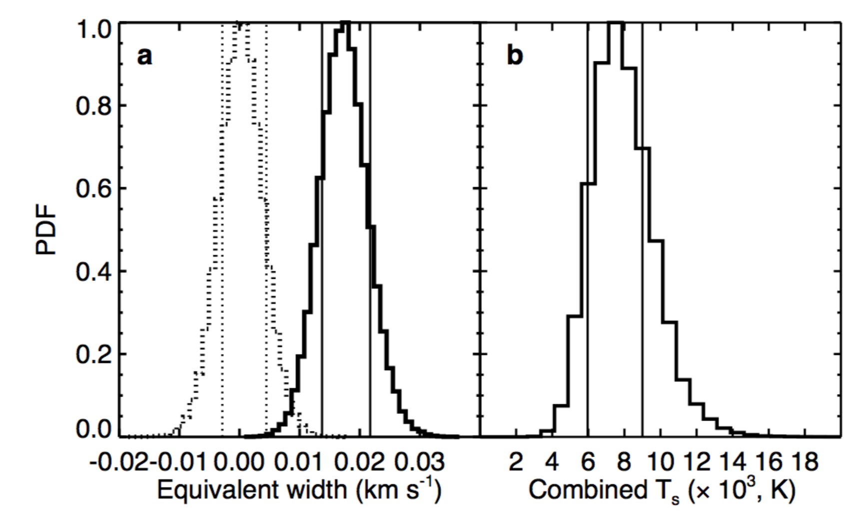
Data	CNM Fraction (Fc)
21SPONGE	median Fc=0.20
Perseus molecular cloud (Stanimirovic et al. 2014)	median Fc=0.33
Synthetic observations of ISM simulation (Kim et al. 2014)	98% LOS: 04<Fc<0.7

- Perseus cloud has higher Fc than random ISM field (21SPONGE).

Murray et al. (2014), submitted

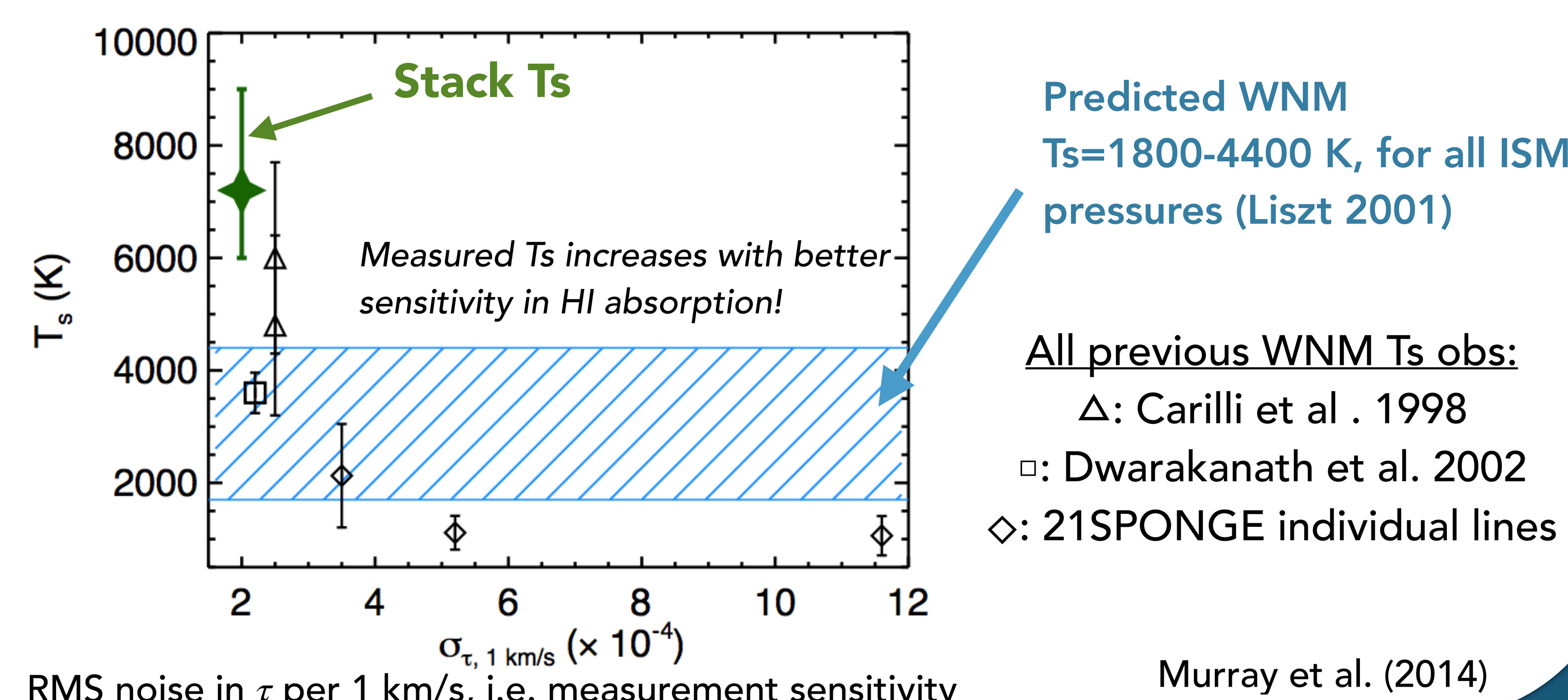
Galactic HI Stacking





Left: Stacked residual emission (a) and absorption (b), following Gaussian models to 19 VLA spectra. **Top**: (a) *solid*: PDF of stacked absorption EW from 10^5 bootstrap trials, *dashed*: same, with 50% sample inverted per trial (verticals=1σ) (b): Ts PDF from bootstrapped trials.

- We stacked the spectral residuals from 21-SPONGE HI models, and detected statistical WNM feature at 5**σ**.
- ⟨Ts⟩ = 7200 (+1800,-1200) K : *higher* than equilibrium model predictions and simulations (e.g. K14 predict Ts~4000K).
- High Ts from stacking (and Carilli et al. 1998) requires higher flux of Lya photons than typically assumed, so that Lya scattering excitation can thermalize WNM Ts~Tk.



Murray et al. (2014)

Conclusions

- We detect less absorbing WNM than we are sensitive to (up to ~8000 K) suggesting that~1000<Ts<8000 K gas is uncommon.
- Molecular cloud environments have higher CNM fractions (Fc) than random ISM fields, although both have *lower* Fc (<0.6) than predictions by simulations (e.g. Kim et al. 2014).
- We statistically measured WNM with Ts=7200K, suggesting a higher Lya flux in the ISM than is commonly assumed.
- Upon completing 21-SPONGE we will: constrain gas fractions in all phases, analyze Ts,WNM as function of environment, and compare with synthetic observations of high-resolution ISM simulations.

References: Dwarakanath et al. 2002 ApJ 567, 940; Carilli et al. 1998 ApJ, 502, L79; Heiles & Troland 2003 ApJS 145, 329; Kim et al. 2014 ApJ 786 64; Murray et al. 2014 ApJ, 781, L41; Roy et al. 2013, MNRAS, 436, 2366; Stanimirovic et al. 2014, ApJ in press.

Acknowledgements: *This work was supported by the National Science Foundation Graduate Research Fellowship and the Wisconsin Space Grant Consortium Graduate Fellowship.*