Properties of the thinnest cold HI clouds in the diffuse ISM

Main Points:

- Very low-N(HI) & small CNM clouds are common in the ISM.
- Suggest existence of large WNM 'envelopes', contributing up to 95-99% of N(HI)_{TOT}.
- Evidence for large # of evaporating, but still long-lived (~1 Myr), CNM clouds.

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Image: Audit & Hennebelle (2005)
Outline:

- **Main motivation:**

- **Recent Arecibo experiment**

- **Properties of ‘thinnest’ cold HI clouds:**
  - Possible cousins to Tiny-Scale Atomic Structure (TSAS)

- **Mechanisms important for low-N(HI) clouds:**
  1. Conductive interface regions between CNM & WNM?
  2. Condensations of WNM in collisions of turbulent flows
  3. General ISM turbulence
  4. Cloud destruction (shock propagation)
1. Motivation: The Millennium Survey

- Heiles & Troland (2003): observed 79 sources; $\Delta T \sim 10^{-3}$, $\Delta N(\text{HI}) \sim 10^{18} \text{ cm}^{-2}$
- CNM: Median $N(\text{HI}) = 0.5 \times 10^{20} \text{ cm}^{-2}$ for $|b| > 10 \text{ deg}$
- CNM: Median $T(\text{spin}) = 48 \text{ K}$ for $|b| > 10 \text{ deg}$
- Excess of CNM components with $N(\text{HI}) < 0.5 \times 10^{20} \text{ cm}^{-2}$

Heiles & Troland (2003)
Many directions with no CNM ...

79 sources in total
16 without detected CNM
26 had $N < 5 \times 10^{19} \text{ cm}^{-2}$
2. Motivation: detection of very weak HI absorption lines


- Very sensitive Westerbork observations: $\Delta \tau \sim 10^{-4}$, peak $\tau \sim 10^{-2}$
- $T_b \sim 2-5$ K, simple l-o-s.
- In emission, a population of discrete clouds:
  - $L = 3 \times 10^3$ AU and $n \sim 10^2$ cm$^{-3}$
  - Confirmed by SS & CH (2005)
- $N(\text{HI}) \sim 1 \times 10^{18}$ cm$^{-2}$

Extremely 'thin' clouds!
How unusual are low-N(HI) clouds?

- **Theory** (McKee & Ostriker 1977): 
  \[ L \sim 2 \text{ pc} (0.4 \rightarrow 10 \text{ pc}), \ N(\text{HI}) \sim 3 \times 10^{20} (0.6 \rightarrow 17) \text{ cm}^{-2} \]

- **Recent Observations** (Heiles & Troland 2003): 
  \[ N(\text{HI}) \sim 5 \times 10^{19} \text{ cm}^{-2} \]

- **Tiny-scale structure:**
  \[ L \sim 30 \text{ AU}, \ N(\text{HI}) \sim \text{a few } \times 10^{18} \text{ to } 10^{19} \text{ cm}^{-2} \]

Questions we want to answer:

- How common are these clouds?
- Is this a new population of IS clouds?
Recent Arecibo observations...searching for low-N(HI) clouds

- **Integration time:** was 1 - 4.5 hrs/source (BEFORE > 15 min).

- **Sources:** HT = 79 sources, 16 without CNM

This work: 22 sources = 10 from HT + 12 non-detections from Dickey et al. (1978) and Crovisier et al. (1980)

- **Detections:** In 10 out of 22 sources new low-N clouds.

DETECTION RATE ~50% !

- **Analyses:** Gaussian decomposition. \( T_{sp} = T_k / 2 \)
More Low-N(HI) Clouds

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**CNM**
- \( \tau = 0.005, 0.003; \)
- fwhm = 3.5, 1.5;
- \( T_k < 270, 50 \text{ K} \)
- \( N < 9 \times 10^{18}, 5 \times 10^{17} \text{ cm}^{-2} \)

**WNM**
- \( T_b \sim 2.5 \text{ K} \)
- \( N \sim 2 \times 10^{20} \text{ cm}^{-2} \)
- \( R = N_{\text{CNM}}/N_{\text{TOT}} = 5\% \)
Properties: very low-N(HI)...

- Medians: \( \tau = 0.01; \) \( \text{FWHM} = 2.4 \text{ km/sec}; \) \( N(\text{HI}) = 3 \times 10^{18} \text{ cm}^{-2} \)

“Low-N(HI) clouds”
Doubled the number of CNM clouds with $N(\text{HI}) < 10^{19}$ cm$^{-2}$...

- PDF of $N(\text{HI})$: $\Psi(N) \propto N^{-1}$

from $N(\text{min}) = 2.6 \times 10^{18}$ to $N(\text{max}) = 2.6 \times 10^{20}$ cm$^{-2}$

----- Heiles & Troland

----- Fit: $\Psi(N) \propto N^{-1}$,
$N(\text{min}) = 3 \times 10^{18}$,
$N(\text{max}) = 3 \times 10^{20}$

----- Low-N clouds
Yet, these clouds seem to fit into the general population of CNM clouds.

----- Heiles & Troland + Low-N clouds

----- Fit: $\Psi(N) \propto N^{-1}$,
$N(\text{min}) = 2.0 \times 10^{18}$,
$N(\text{max}) = 2.6 \times 10^{20}$
Seem to be associated with large WNM 'envelopes'

- $R = \frac{N_{\text{CNM}}}{N_{\text{TOT}}}$.
- WNM contributes >90-95% of total HI in these l-o-s.
Low-N(HI) clouds must be small...

- If \( n(HI)T \approx 3000 \text{ K cm}^{-3} \) then \( n(HI) \approx 20-100 \text{ cm}^{-3} \)
- \( L(||) = N(HI)/n(HI) \approx 800-4000 \text{ AU} \).
- If \( n(HI)T > 3000 \text{ K} \), then \( L(||) < 800-4000 \text{ AU} \).


- compact HI clumps in emission: \( L=3\times10^3 \text{ AU} \) and \( n\approx10^2 \text{ cm}^{-3} \)
- Evidence for injection of fluctuations on small scales.
- Origin in stellar winds (shell)?
Traditional CNM clouds vs ‘thin’ clouds vs TSAS…

• Could be an extension of the traditional population of CNM clouds, bridging the gap between CNM CLOUDS and TSAS.
• Could be sampling different ends of the same class.
Which mechanisms can produce clouds with \( N(\text{HI}) \sim 10^{18} \text{ cm}^{-2} \)?

- **Conductive heat transfer** at interface regions between the cold and warm neutral medium?

- **Condensation of warm medium in collisions of turbulent flows** (Audit & Hennebelle 2005)?

- **General ISM turbulence**?
  (Vazquez-Semadeni et al. 1997)

- **CNM destruction by shocks**? (Nakamura et al. 2005)
**Evaporation vs Condensation**

**Classical Evaporation Theory McKee & Cowie (1977):**

For WNM with $T \sim 10^2-10^4$ K, cloud critical radius is $\sim 6000$ AU.
Size $< 6000$AU --> evaporation
Size $> 6000$AU --> condensation of WNM.

⇒ Low N(HI) allowed if CNM is surrounded by WNM with $T \sim 10^2-10^4$ K.

⇒ But, low-N clouds are evaporating, this can take up to $10^6$ years.

[Agrees with Nagashima et al. 06]
Formation of CNM clouds in collision of turbulent WNM streams

CNM properties:
- $n \sim 50 \, \text{cm}^{-3}$
- $T \sim 80 \, \text{K}$
- $R \sim 0.02-0.1 \, \text{pc}$

Small, low-N CNM clouds can form in WNM condensation

Turbulence determines cloud properties

Audit & Hennebelle (2005)
Cloud destruction by shock propagation:

- Nakamura, McKee et al. (2005): a spray of small HI ‘shreds’ is formed due to hydrodynamic instabilities. Could be related to low-N clouds.

- ‘Shreds’ have large aspect ratios, up to 2000!

- “Since we don’t take into account the magnetic fields, we cannot compare our results quantitatively with observations.”
Summary:

- CNM clouds with N(HI) ~10^{18} cm^{-2} are common in the ISM. These clouds are very thin, L(\|) ~800-4000 AU.

- They are evaporating very fast, unless are surrounded by a lot of mild WNM, T~10^2 - 10^4 K, in which case could last for up to ~1 Myr.

- Evidence for large WNM ‘envelopes’ which contribute up to 95-99% of the total N(HI).

- Evidence for large # of evaporating, but still long-lived, CNM clouds.

- Encouraging agreement with some recent numerical simulations.

- A lot of CNM clouds may be more transient than what’s traditionally assumed (discrete, permanent features).
Suggestions for models/simulations (what’s badly needed for comparison with observations):

- sizes, aspect ratios, morphology
- column densities
- temperature
- $N_{\text{CNM}}/N_{\text{WNM}}$
- lifetime
The End