Constraining Properties of Evolving Cold Interstellar Clouds

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1. Interstellar Medium

- Area between stars containing mix of gas and dust (small solid particles)
- Small percentage of galactic mass, but critical role in galaxy's development
- Composition: 90.8% Hydrogen atoms, 9.1% Helium, 0.12% heavier elements; we focus on Hydrogen here.
- Different gas temperatures ($10 - 10^6$ K) in different "phases" (H_2, HI, HII)
- Gas and dust form new stars, which later return material to their environment.
- Cold interstellar clouds are denser regions that can form stars.
- We want to understand their structure and dynamics.

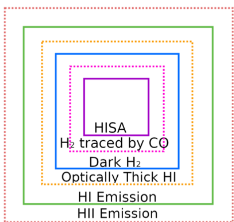

Fig. 1. *Onion-skin model of cloud*

2. HI Self-Absorption (HISA)

- HI 21 cm line emission arises from warm gas behind cold cloud.
- This is absorbed by the cold cloud when passing through it.
- The absorption shows up as a narrow "dip" in the emission line.

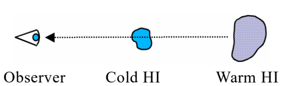

Fig. 4. *Line of sight through HISA cloud*

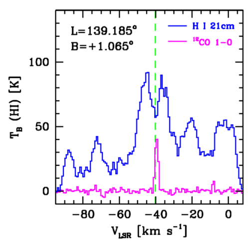

Fig. 3. *HI and CO spectra near map center in Fig 2, with HISA at –40 km/s*

3. Properties

- f_n – fraction of hydrogen particles that are neutral atoms, not molecules
- X_{CO} – molecular gas scaling factor – The amount of H_2 traced by CO is equal to X_{CO} multiplied by the ^{12}CO 2.6 mm emission line brightness, integrated over its velocity range:
  - $N_{H_2,CO} = X_{CO} \int T_{B\,^{12}CO}(v)dv$
- H_2 cannot be mapped directly, since it doesn't emit when cold.
- H_2 not traced by CO is called *dark molecular gas*.
- X_{EBV} – gas-to-dust scaling factor – The total hydrogen column density (hydrogen atoms per cm^2 along the line of sight) traced by dust is equal to X_{EBV} multiplied by E_{B-V}, the reddening of starlight due to dust:
  - $N_{H,dust} = X_{EBV} E_{B-V} = 2N_{H2} + N_{HI} + N_{HII}$

4. Model

- For simplicity, assume cloud has nested rectangular structure in **Fig. 1**.
- Numerically modeled radiative transfer through cells with different properties, including temperature, density
- Used ideal gas law to keep temperature and density consistent with pressure equilibrium
- Made synthetic observations of 21cm line absorption and emission to test analysis

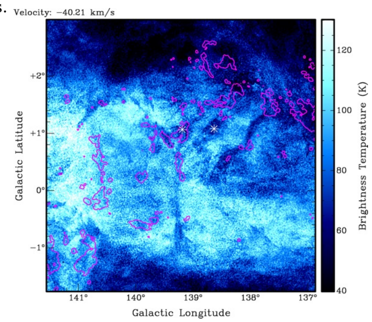

Fig. 2. *Perseus HISA Complex with background HI emission, CO contours*

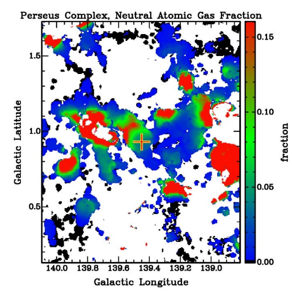

Fig. 7. *Calculated atomic fraction (f_n) for Perseus HISA Complex*

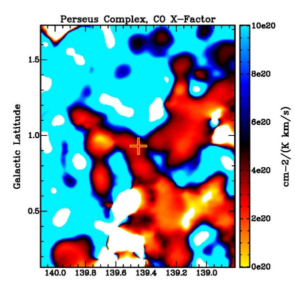

Fig. 8. *Calculated molecular scaling factor (X_{CO}) for Perseus HISA Complex*

5. Perseus HISA Complex Analysis

- Analyzed Perseus HISA Cloud Complex to help constrain parameter values
  - Chose well-studied area to test analysis
- Used HI data from CGPS, CO data from OGS, dust images from *Planck* satellite
- Used ideal gas relations
- Mapped possible f_n, X_{CO} values from different X_{EBV} input values to find range of likely values for parameters.

6. Results

- Assuming standard value of gas-to-dust scaling factor $X_{EBV} = 5.8 * 10^{21}$ cm^{-2} mag^{-1}, we obtain
  - $f_n = 0.037$
  - $X_{CO} = 2.9 * 10^{20}$ cm^{-2} / (K km/s)
- From these results, we find that
  - Fraction of H_2 traced by CO = 0.68
  - HISA gas temperature = 32.2 K

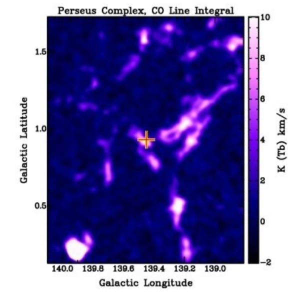

Fig. 5. *Perseus HISA Complex CO line integral*

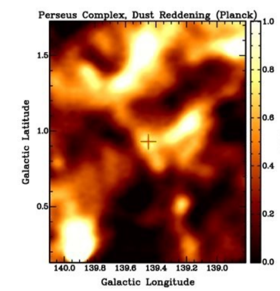

Fig. 6. *Perseus HISA Complex dust content*

7. Conclusions and Future Work

- Scaling factors reasonably consistent with literature values.
- The Perseus HISA Complex is cold and mostly molecular.
- It contains a significant amount of dark gas.
- Properties consistent with evolving clouds prior to star formation
- Plan to use higher angular resolution data (1-2 arcminutes vs 5-6).
- Also plan to analyze other cold clouds throughout the galaxy.

8. References

- Beauchamp & Gibson 2023, WKU-SSS
- Gibson et al. 2018, JAXA-SP-17-009E, 397
- Gibson et al. 2000, ApJ, 540, 851
- Heyer et al. 1998, ApJS, 115, 241
- Planck Collab. 2016, A&A, 586, A132
- Taylor et al. 2003, AJ, 125, 3145

9. Acknowledgements

- This work was funded by NASA KY EPSCoR RID award 3200004560-23-206.
- Data sources:
  - HI: Canadian Galactic Plane Survey (DRAO)
  - CO: Outer Galaxy Survey (FCRAO)
  - Dust: *Planck Space Telescope* (ESA)