Tracing the Mass Distribution in Star-Forming Cores Using Ammonia

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Abstract

Through the assumption of a slowly varying partition function for ammonia in the temperature regime typically found in star forming regions, we have mapped the mass distribution around a number of cores in W3 and Perseus. This assumption allows us to determine the column density of ammonia using only the (1,1) inversion transition rather than the typical combination of the (1,1) and (2,2) transitions. We present the resulting column density maps along with a comparison to the corresponding maps created using the established method. We suggest that this method is a useful tool in studying the distribution of mass around YSOs, particularly in the outskirts of the envelope where the (2,2) ammonia line is not always detectable on the short timescales necessary for large area mapping.

Background

The usefulness of ammonia as a tracer of conditions in the interstellar medium (ISM) has been recognised for many years (e.g. Ziurys et al 1981; Martin & Barrett, 1978; Cheung et al, 1968). The (1,1) and (2,2) rotational inversion transitions trace conditions typical for star-forming regions (e.g. Larson, 2003) and therefore ammonia has become a useful tool in the study of young stellar objects (YSOs), (e.g., Morgan et al, 2010; Freisen et al, 2009; Rosolowsky et al, 2008).

The combination of optical depth and temperature measurements made possible by the hyperfine structure of the (1,1) transition and ratio of the (2,2) transition allow for the column density of molecular gas to be determined through commonly used methods (Ho & Townes, 1983) and the assumption of LTE. Through this application, the mass distribution of molecular gas in the dense ISM may be mapped. However, optical depth is likely to be observable over a greater spatial region than the rotational/kinetic temperature. This leads to a limitation on the amount of potentially star-forming material for which column density may be determined, despite the detection of ammonia in the (1,1) transition.

Method

The column density of ammonia is reliant upon the detection of the (2,2) transition due to the reliance of the partition function,

$$Z = \sum_{J}^{\infty} (2J+1)\, S(J)\, exp\left\{-h\frac{[BJ(J+1)-(C-B)J^2]}{kT_k}\right\},$$

upon kinetic temperature (T_k)

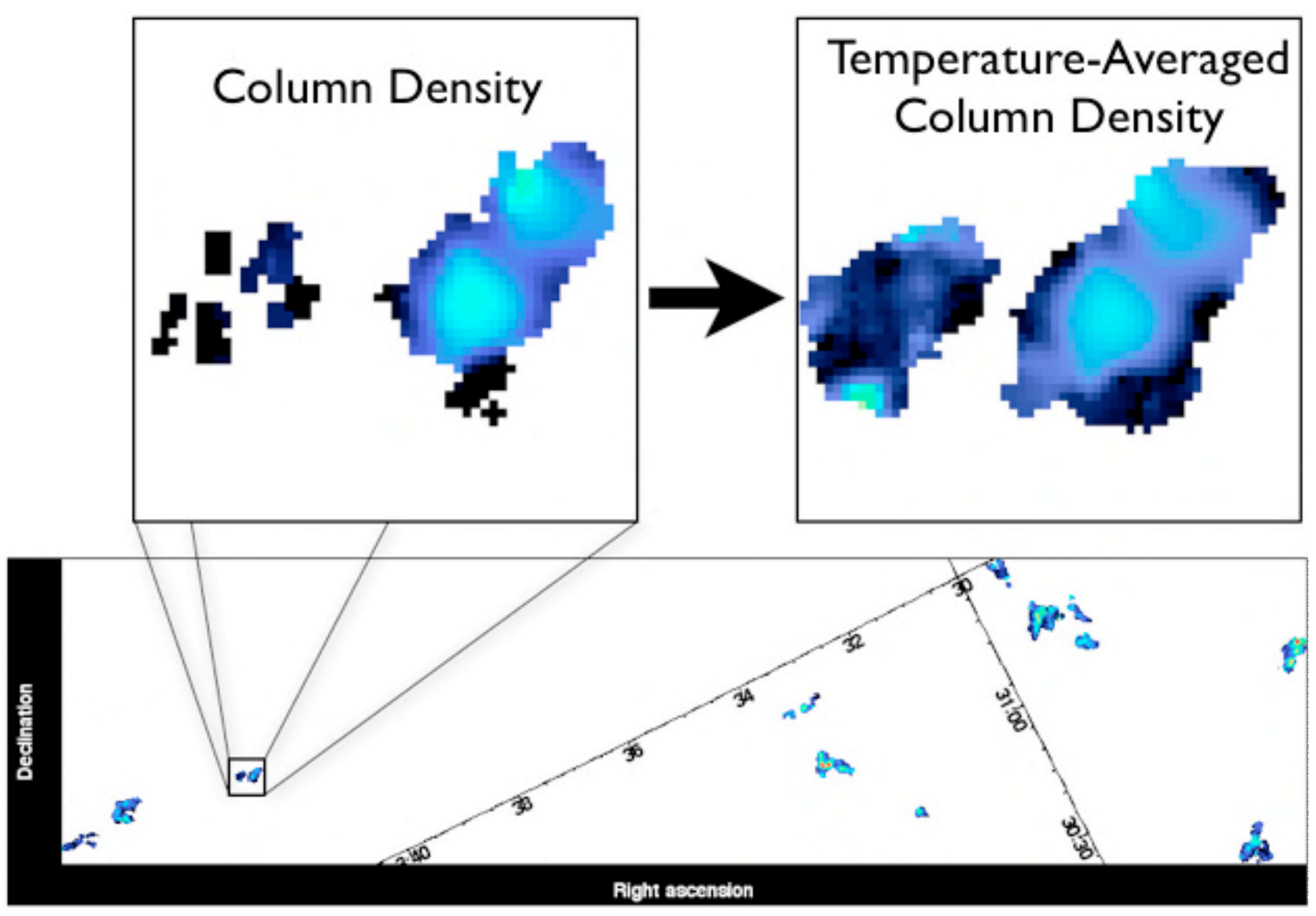

Fig. 1
Map of the distribution of ammonia gas in Perseus, as determined through the described assumption of a mean kinetic temperature. The zoom boxes show the comparison of the column density distribution as determined through the traditional method (left) and through the assumption of a mean kinetic temperature (right)

Temperature Range

The kinetic temperature of interstellar ammonia may be determined from the rotation temperature, derived through the equation

$$T_r = \frac{-T_0}{ln\left[-\frac{0.282}{\tau_{m(1,1)}} ln\left\{1-\frac{\Delta T_{Am(2,2)}}{\Delta T_{Am(1,1)}}\left[1-e^{-\tau_{m(1,1)}}\right]\right\}\right]}$$

In order to determine a reasonable range of T_k for which the partition function must be defined, we have examined the ammonia maps of Perseus and W3 presented in Morgan et al (*in progress*) in addition to other works.

Solving for T_r over the physically relevant ranges of $T_A^*(2,2)/T_A^*(1,1)$ and τ_m allows us to identify a plane of solutions applicable to star-forming regions. The equilibrium solutions of this plane result in a variation of T_r between 8.7 and 32.8 K, corresponding to a kinetic temperature range of 8.9 - 45.5 K.

Discussion

Over our expected kinetic temperature range, we may expect the partition function to vary by as much as a factor of 2.5, even in relatively extreme star-forming conditions. This essentially small variation in column density related to temperature means that column density could well be calculated with the assumption of a mean temperature without any great loss of precision. This then allows column density to be determined for regions which do not have adequate SNRs in the (2,2) transition for kinetic temperature measurements.

Performing the described derivation of temperature-averaged column density for the Perseus and W3 ammonia cores presented in Morgan et al (*in progress)* results in maps tracing ammonia distribution (Fig. 1). We compared these maps to maps of column density derived from the traditional analysis. It was found that the total area mapped can be increased by a factor of 20-30% through use of the proposed temperature-averaging method. An example of this beneficial increase can be seen in the zoom boxes of Fig. 1 in which the column density map of a star-forming core in Perseus is compared to the equivalent map derived from the temperature-averaging method.

A careful comparison of column densities derived through both the traditional and temperature-averaging methods reveals that variations between derived values are less than 30% to a three-sigma completeness level. This indicates that the proposed method provides valid measurements of column density in regions where such measurements would not otherwise be possible.

Conclusions

The proposed method of deriving column density through the assumption of an average temperature provides a way for the mass distribution in star formation regions to be traced over a significantly greater regime than previously possible. The accuracy of column density measurements made through the assumption of a mean temperature is comparable to measurements made with full knowledge of temperature.

The simple assumption of a mean temperature then, has significantly increased the efficiency of mapping in ammonia. These extended regions of emission are important to studies of star formation in many ways, not least in studies of the relation of submillimetre continuum emission to gas mass, the abundances of nitrogen Vs. carbon bearing molecular species and the variance of virial ratios in different regions (Morgan et al, *in progress).*