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AST424 project report: Complex Molecules as Core Stability Indicators

Ruyi Xu[1]

Dr. Duo Xu[2] And Dr. Rachel Friesen[2]

[1] *Student Number 1007707091*
[2] *Project Supervisors*

ABSTRACT

We present the relationship between stability and complex molecules in the regions of Perseus B1, Taurus B18 and HC2. Here we utilise HC_5N, C_2S and NH_3 emission data from the Green Bank Telescope's (GBT) Greenbank Ammonia Survey (GAS), ^{13}CO data from the Five College Radio Astronomical Observatory and the 850 μm dust emission data from the James Clerk Maxwell Telescope (JCMT). We find that there is a positive correlation between the abundance of complex molecules with each other between complex molecules and stability in our analysis. We also find similarities in the abundance and stability comparisons between HC_5N, C_2S suggesting a similar formation mechanism between the 2 and also that most cores in the regions are stable. Due to time constraints, further analysis with pressure is not completed yet.

1. PROJECT DETAILS

1.1. *Background*

Dense cores in star-forming regions are believed to be sites for star formation, and their stability determines whether they collapse to form stars or dissipate. Complex molecules such as HC_5N, and C_2S can be used to determine the mass of the core by relating to the abundance of H giving insights into the mass and the potential energy aspect of the virial stability.

Currently, most research looks into the gas-phase chemistry of such star-forming regions for our purposes we will be looking into gas grain models with NH_3 and check if there is a relationship between the abundance of C_2S, HC_5N and the virial stability. As such we utilise available gas phase model results with CO to cross-check our results of H abundance derived from NH_3 and then identify the correlation between abundances of more complex molecules against the stability of cores.

1.2. *Project Overview*

In this project we will examine the virial stability of star-forming regions in the Taurus and Perseus regions using complex molecules and ammonia detected by the GBT Greenbank Ammonia survey (GAS) and presented in **?**, Carbon Monoxide detected by FCRAO in Perseus Goodman et al. (2005) and Taurus Narayanan et al. (2008) and dust emission from JCMT Kirk et al. (2018). To identify clusters for studying we will use Agglomerative Clustering for ORganising Nested Structures (ACORNS Henshaw et al. 2020) followed by determining the mass of the cluster by using formulas for column density from Wilson et al. (2013), Kerr et al. (2019) and Mangum & Shirley (2015) and then using the mass to determine the virial stability of identified clusters. Based on current work we are inclined to say that there is a high possibility that we have a positive correlation between the abundance of complex molecules and core stability.

In our study, we identified 25 cores in the Taurus HC2 and B18 region and the Perseus B1 region. In comparing the virial parameter, we found that most of these cores are stable and that there is a trend towards increasing stability with increasing amounts of complex molecules.

2. DETAILS OF PROCEDURES

2.1. *Reprojection and Spectral Integration*

For the cropping and reprojection of data to the same coordinates, we will use the package Reproject. Here we will produce 2 types of reprojection; masked and non-masked. Masked projections will follow the regions of available GBT data, this will be used for our computations and analysis. The non-masked data will include the whole square area of the GBT data (see Fig.4) and this will be used to confirm that there are no offsets or branching emissions that are missed out. For FCRAO CO data we are given spectral maps of the emission thus we will need to integrate it with the package Spectral Cube. The calculation of moments and FWHM is as follows:

$$\text{Moment 0 (intensity)} = \int I_v dv$$

$$\text{Moment 1 (velocity)} = \frac{\int v I_v dv}{\int I_v dv}$$

$$\text{Moment 2 (velocity dispersion)} = \frac{\int I_v (v - \int I_v dv)^2 dv}{\int I_v dv}$$

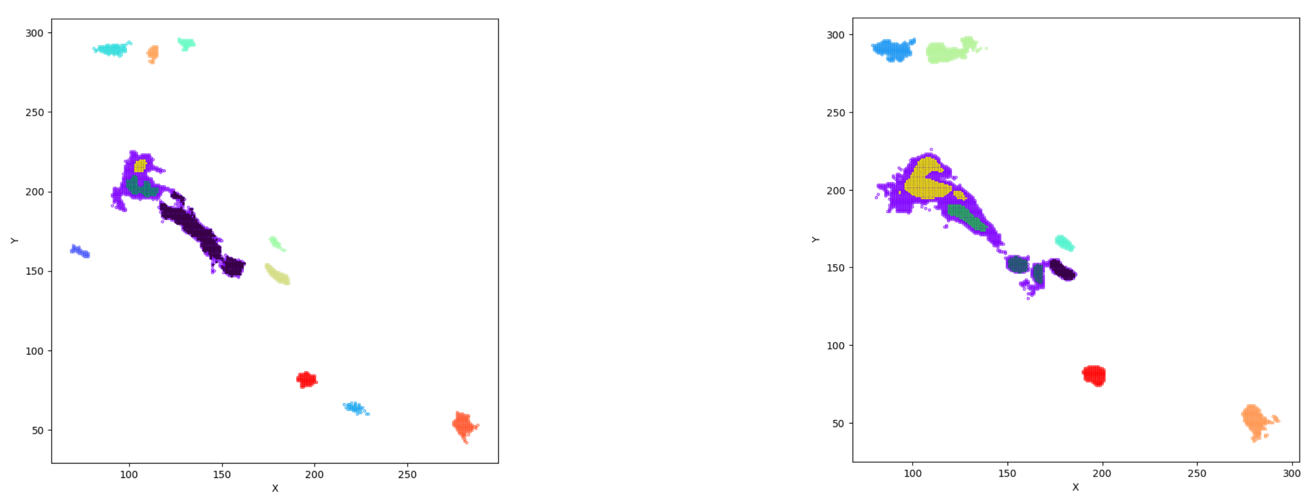
Some results can be seen in Fig.5

2.2. *Cores Identification*

For the identification of Cores, we use ACORNS Henshaw et al. (2020) a bottom-up agglomeration package that identifies clumps of distinct materials to group them into a tree leaf diagram based on our desired parameters. For this project, the parameters used for HC_5N, C_2S, NH_3 and JCMT Dust are found in table 1. The `pixel_zize` is given by the ratio for pixels to coordinates, `min_radius` is provided by the number of pixels to cover the beam size, `min_height` is the minimum intensity to be accepted as data points, `stopping criteria` is the desired minimum SNR ratio desired. In Fig.6 we have some sample clusters identified in HC2.

In this project, we will use clusters identified in $850\mu m$ JCMT Dust emission as cores for analysis. We have decided to make dust our main marker since dust is currently the best indicator available to us to determine star-forming cores. Cores identified in GBT HC_5N, C_2S, NH_3 will only be used to cross-check and confirm the location and rough shape of cores in which for our project they agree with cores found in JCMT Dust as seen in Fig. 1 we see that the cores found agree with each other. The selection of stopping criteria and minimum height is arbitrary since we want non-nested cores (i.e. cores identified as a single core and not part of a bigger one) and hence a trial and error method is used to select the best parameters. We will then use each of the cores to mask the projected data to obtain emission data of other molecules in the identified dust core.

Figure 1: Perseus B1 region JCMT Dust cores (left) and GBT NH_3 cores (right)



2.3. *Finding column density*

For the calculation of column density, we will need to refer to equations and parameters found empirically in past works, for NH_3 the equation is obtained from Kerr et al. (2019)

$$N(1,1) = \frac{8\pi\nu_0^2 g_1}{c^2 g_2 A(1,1)} \times \frac{1+\exp\left(-\frac{h\nu_0}{kT_{ex}}\right)}{1-\exp\left(-\frac{h\nu_0}{kT_{ex}}\right)} \int \tau(\nu) d\nu \tag{1}$$

For HC_5N and C_2S we it is found in Mangum & Shirley (2015)

$$N = \frac{8\pi k\nu_0}{hc^2}\frac{g_1}{g_2 A_{ul}}\sqrt{2\pi\sigma_v}\left[J(T_{ex}) - J(T_{bg})\right]\tau_{ul} \tag{2}$$

and for CO it is found in Wilson et al. (2013)

$$N(\text{total})^{13}_{\text{CO}} = 3.0 \times 10^{14} \frac{T\int \tau^{13}(V)\, dV}{1-\exp\{-5.3/T\}} \tag{3}$$

2.4. *Abundance ratio and virial parameters*

For abundance ratios it will also come from observational data for example in the UMIST astrochemistry database by McElroy et al. (2013). Using these ratios and the column density map we can calculate the mass of each cluster which will be used in the kinetic, gravitational and pressure virial parameter calculations from Kirk et al. (2017)

$$\Omega_k = \frac{3}{2} M\sigma_{\text{tot}}^2, \tag{4}$$

$$\Omega_g = -\frac{1}{2\sqrt{\pi}}\frac{GM^2}{R}, \tag{5}$$

$$\Omega_p = -4\pi P R^3, \tag{6}$$

Where P, σ_{tot} is given by

$$\sigma_{tot} = \sqrt{\sigma_{obs}^2 - \frac{k_B T_{kin}}{\mu_X m_H} + \frac{k_B T_{kin}}{\mu_{mean} m_H}} \tag{4}$$

$$P = P_{cloud} + P_{turb} + P_{BE} \tag{5}$$

$$P_{cloud} = \pi G\bar{\Sigma}\Sigma \tag{6}$$

$$P_{turb} = \rho_{turb}\sigma_{tot}^2 \tag{7}$$

$$P_{BE} = 1.40\frac{c_s^8}{G^3 M^2} \tag{8}$$

σ_{tot} is the total velocity dispersion found by adding the kinetic velocity dispersion of gas in the region and subtracting off the specific molecule velocity dispersion to remove double counting, for our study we will be using NH_3 to determine the velocity dispersion of cores. Pressure is made up of the cloud weight pressure P_{cloud} computed by the product of average column density $\bar{\Sigma}$ and specific column density Σ, Turbulent Pressure P_{turb} is found as the product of the density of the cloud and their velocity dispersion and lastly the Bonnor-Ebert sphere pressure P_{BE} where c_s is the speed of sound.

For simplicity's sake (and a lack of time to compute pressure) for stability, we will check the virial parameter α given by

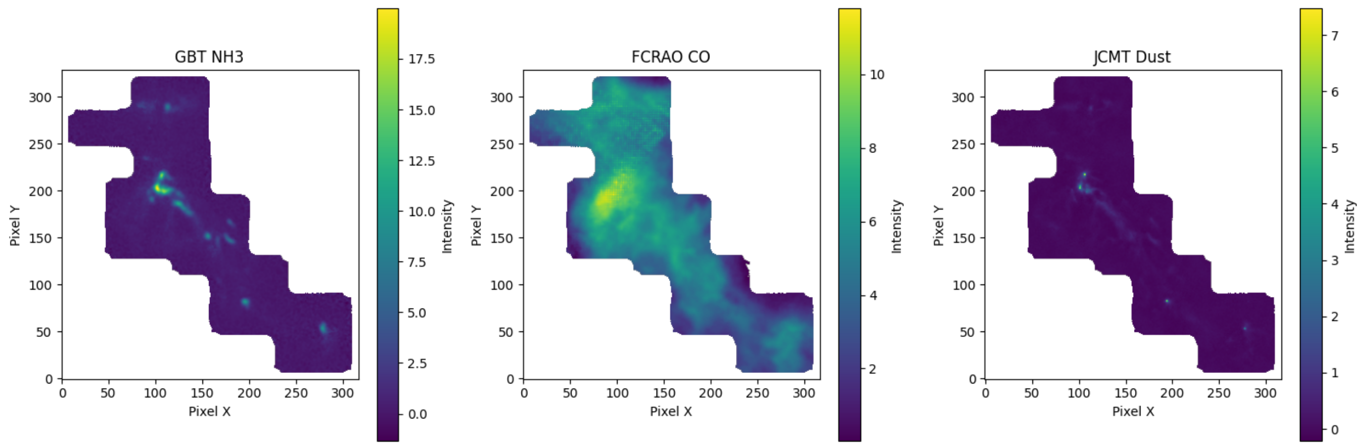
$$\alpha = \frac{5\sigma_{tot}^2 R}{GM} \tag{9}$$

Where any value below 2 will be stable.

3. RESULTS

By inspection of intensities across NH_3, CO and dust data from the 3 telescopes.

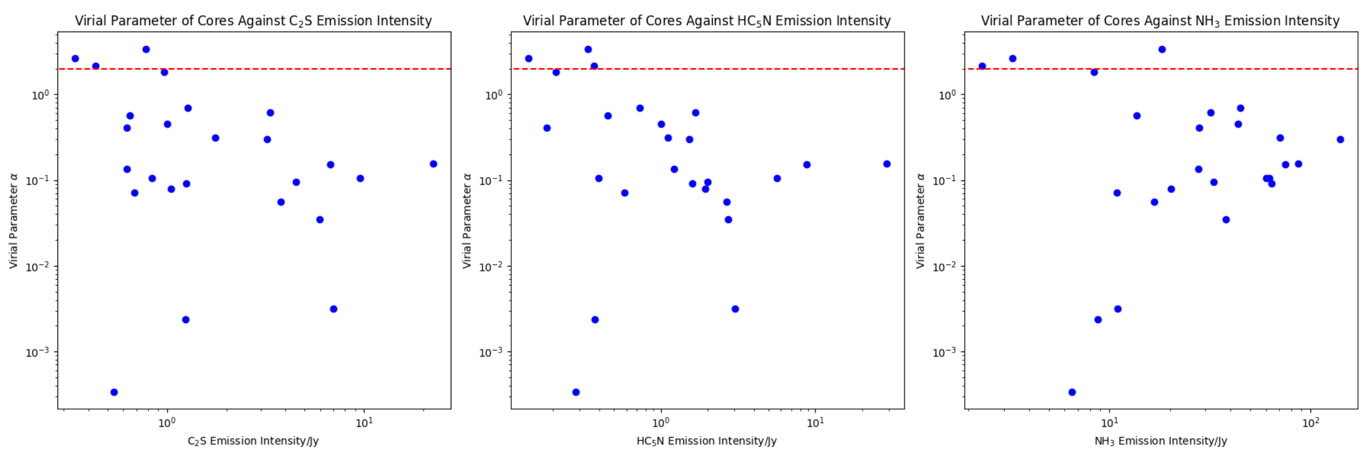
Figure 2: Intensities for GBT NH_3, FCRAO CO and JCMT Dust



We can see that there is a good correlation between the NH_3 and dust data and with closer scrutiny although more diffuse CO also relates very well with NH_3 and dust results as well. For example, most prominently we have a significant core at (100,200) which matches across all 3 Telescopes, at (275,50) we can see that CO becomes fainter at (225,50) before becoming brighter around (275,50) signifying that this is very likely a distinct core. The same goes with the cores at (125,275) and (200,75)

Computing the Virial parameters for all the cores and plotting them against the intensities of complex molecules we get,

Figure 3: Virial Parameters α against detected intensities ($\alpha < 2$ implies stable)



Here on visual inspection, we can confirm that there is a positive relation between stability and abundance of complex molecules. One interesting feature to note is the similarities between HC_5N and C_2S plots against the virial parameter are similar in their distribution, possibly indicating an abundance relation between the 2 and a connection in its chemical mechanisms.

4. DISCUSSION

4.1. *Assumptions and Inaccuracies*

In our study, we have made several significant assumptions such as

- Assumption of uniform empirical values across the region
- Assumption of spherical shape for all cores
- Assumption the pressure is not affected by electromagnetic effects and filament pressure
- velocity dispersion, temperature of one molecule represents the velocity dispersion of the whole core

Other than this in our virial parameter analysis, we see that most cores are stable which should not be the case when composing against a similar analysis in Kirk et al. (2017) where roughly around half of the cores are unstable. Here it is likely that by using NH_3 velocity dispersion which is lower than other typical molecules used for velocity dispersion such as CO (not used here in our study due to high levels of noise as seen in the upper region of fig 7 As such to improve our study an alternative source for determining velocity dispersion will be essential.

4.2. *Future Work*

Future work will include computing pressure parameters for the cores and making stability comparisons including the pressure components of the cores. Another improvement that can be made is to look at the velocity of each core and determine if they are rotating and include their rotational kinetic energies in our stability computations as well which will improve our virial parameter stability results as several cores will have higher kinetic components.
Another major improvement that can be made is to look at the magnetic field properties and relations to each of the core stability such as the one performed on cores in Orion in Li et al. (2022) which can give insights into more electromagnetic dynamics of chemical mechanisms of such complex molecules.

APPENDIX

A. FIGURES

Figure 4: Masked(right) and unmasked(left) projection of JCMT B1 dust Emission

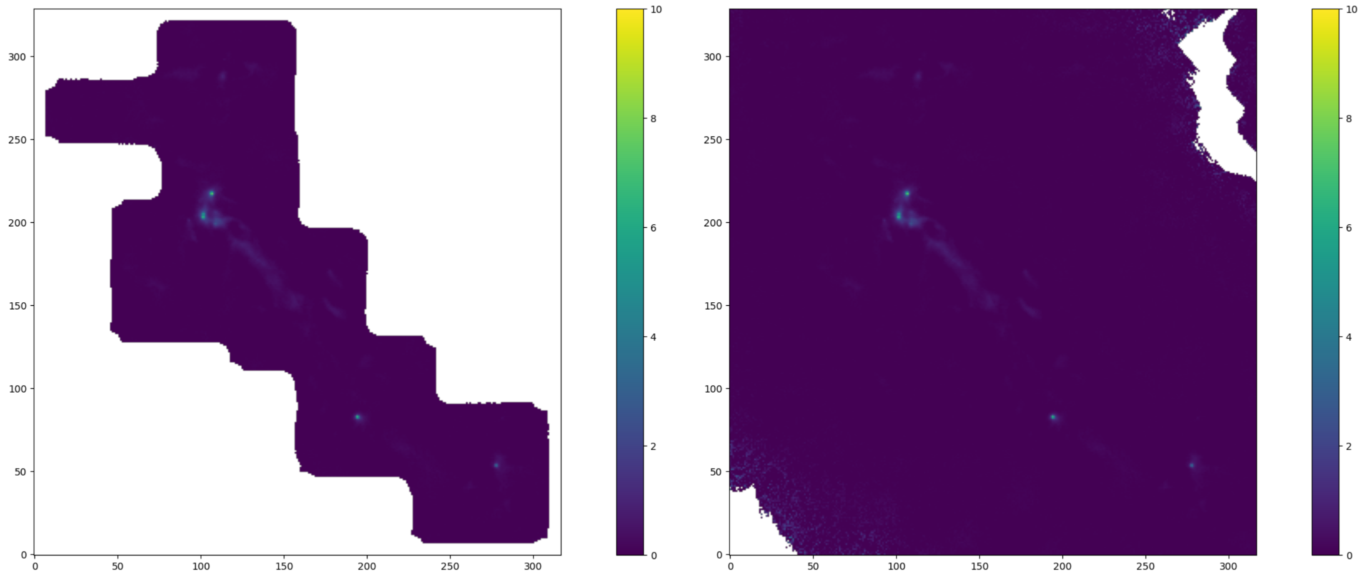


Figure 5: Mom0,Mom1,Mom2 of FCRAO HC2 CO13 gas Emission

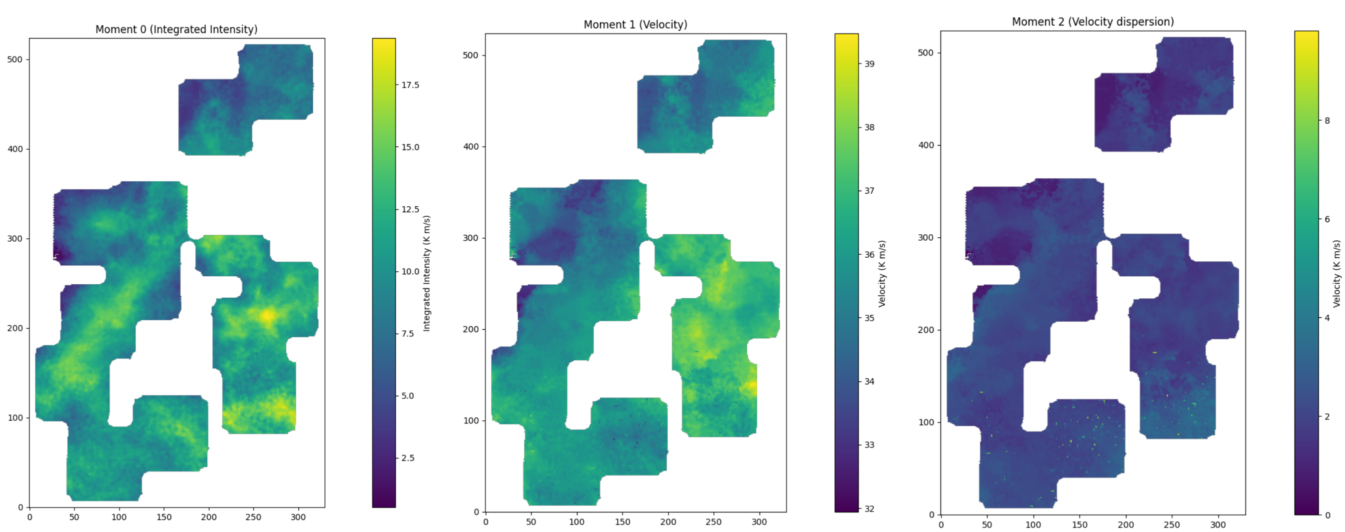


Figure 6: clusters of molecules found in HC2

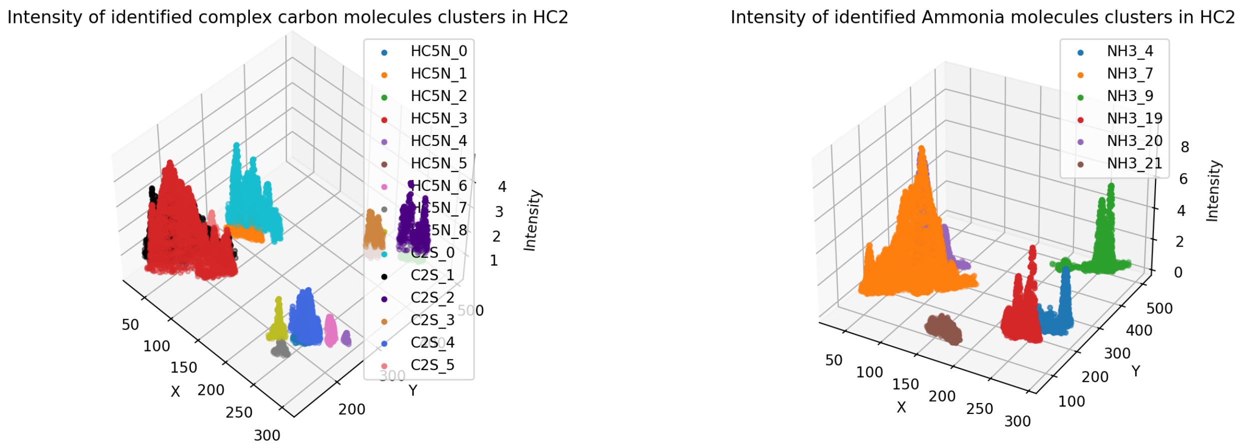
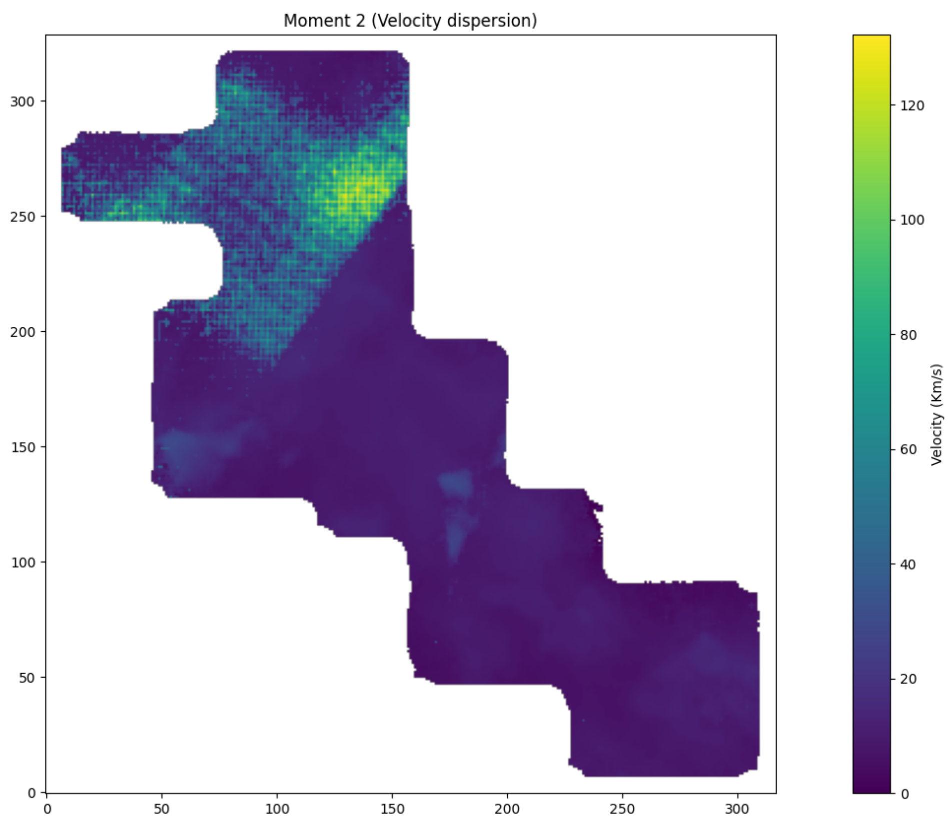


Figure 7: Moment 2 Velocity dispersion of CO13 in Perseus B1 with high noise in upper region



B. TABLES

Table 1: Table of parameters used for the identification of clusters.

	GBT HC_5N,C_2S and NH_3	JCMT Dust
pixel_size	1	1
min_radius	3.6	2.12
min_height	3*(rmsnoise)	3*(rmsnoise)
stopping criteria	3	1

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