A Catalog of Southern Molecular Clouds in ThrUMMS

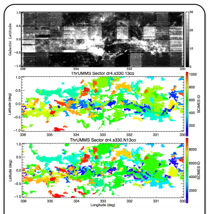
Audra K. Hernandez[1], Peter J. Barnes[2], Ana Duarte-Cabral[3], Erik Muller[4] , & Bob Benjamin[5]

1. University of Wisconsin – Madison , 2. University of Florida & University of New England (AU) , 3. Cardiff University,
4. National Astronomical Observatory of Japan, 5. University of Wisconsin-Whitewater

Email: hernande@astro.wisc.edu

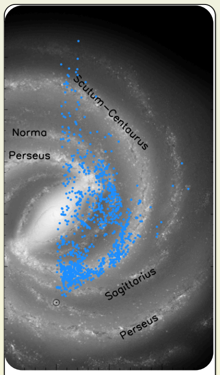
Overview

The **T**hree-mm **U**ltimate **M**opra **M**ilky **W**ay **S**urvey (**ThrUMMS**) provides a uniform and unbiased mapping of a 60° X 2° region of our Galaxy's southern plane (4Q) in three CO isotopologues and CN. We present a new catalog of southern molecular clouds identified from the ^{13}CO (J=1-0) data. We have applied the **SCIMES** (**S**pectral **C**lustering for **I**nterstellar **M**olecular **E**mission **S**egmentation; Colombo et al. 2015) dendrogram algorithm to construct our catalog using two different cloud extraction methods. First, we compiled an intensity based cloud extraction (I_{ex}), focusing on 6° X 2° sectors at a time. The ^{13}CO (1-0) data was binned to a velocity resolution of ~0.37 km/s, an ~1' spatial resolution (24" binning). Although ThrUMMS has a limited sensitivity due to its fast mapping techniques (see Barnes et al. 2015), we are interested in cataloging larger cloud complexes (e.g., giant molecular cloud scale). Therefore, using an RMS noise limit of σ~0.8 K per channel for the dendrogram tree construction, we set a 2.5σ detection limit to maximize the connection between continuous lower limit intensity structures and a 4σ minimum separation difference between neighboring leaf peaks. The SCIMES configuration was set to consider both intensity and volume during clustering. Secondly, inspired by current galactic disk and molecular cloud models that define cloud structures based on simulated mass or mass density data cubes, we perform a column density based extraction (N_{ex}). The ^{13}CO (1-0) intensity data was converted into CO column density cubes by estimating the excitation temperature in each voxel from the ThrUMMS ^{12}CO (1-0) data. The SCIMES detection and clustering limits from the I_{ex} extraction were retained by converted to column density limits assuming a mean cloud voxel T_{ex} of 7 K. A visual representation of the clouds found within one 6° X 2° ThrUMMS sector for both our extraction methods are shown in the figure to the left.

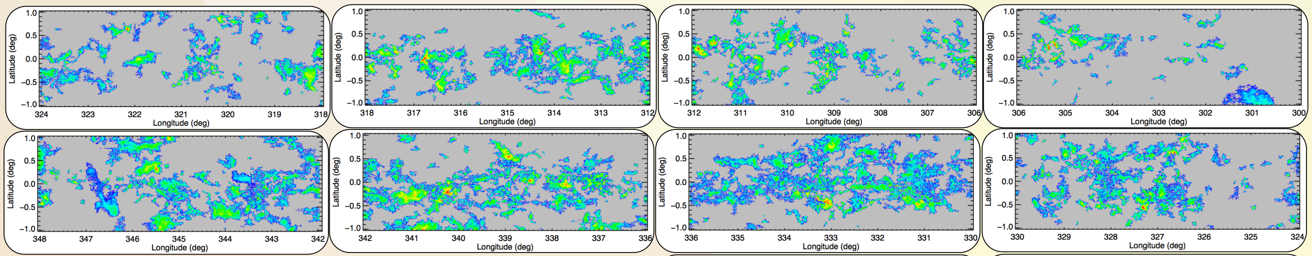


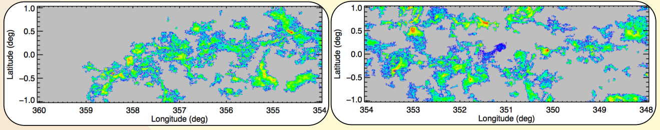
A visual representation of the molecular clouds found within one 6° X 2° ThrUMMS sector. The top panel shows the total ^{13}CO integrated intensity (dv=-150-50 km s^{-1}) and the cloud masks for the I_{ex} (middle) and N_{ex} (bottom) extractions are shown below (their color corresponds to their SCIMES ID).

For the I_{ex} extraction method we find a total of 1,278 molecular clouds, of which 408 are clusters (i.e., comprised of at least 2 dendrogram leaves). For the N_{ex} extraction, we find a total of 1,833 molecular clouds, of which 1,205 are clusters. The figure to the right presents the estimated kinematic distance for each I_{ex} molecular cloud as projected onto the plane of the Southern Milky Way. Kinematic distances were estimated using the Bayesian distance calculator from the BeSSeL Survey (see Reid et al. 2016). Overall, the spatial distribution of the clouds aligns well with the Galactic spiral structure, especially the Scutum-Centaurus and Norma arms. The figure below presents the ^{13}CO integrated intensity (K km s^{-1}) maps for all clouds found within the ThrUMMS Survey.



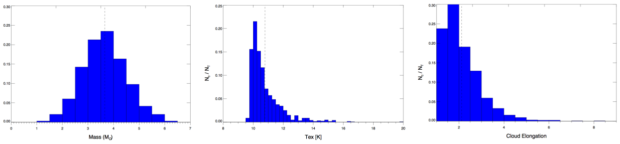
The spatial distribution of the I_{ex} extracted SCIMES molecular clouds overlaid on a face-on Milky Way composite image (Robert Hurt of the Spitzer Science Center with consultation from Bob Benjamin). The cloud center positions are shown by the blue points. The location of the Sun ($R_{\odot}$=8.34 kpc) is shown by the ⊙ symbol.





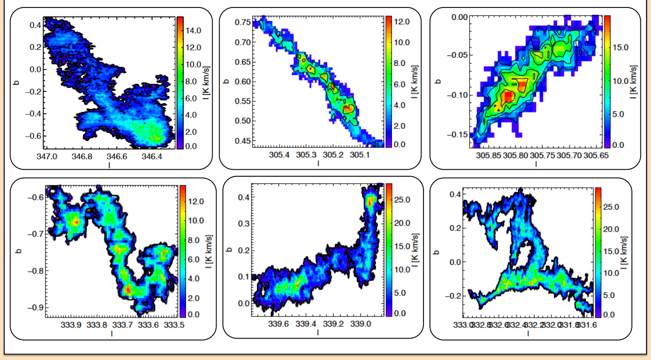
Molecular Cloud Physical Properties

We estimated the total H_2 cloud masses using an $n^{12}CO/n^{13}CO$ abundance model from Milam et al. (2005) and an $n_{12}CO/n_{H2}$ abundance of 2 × 10^{-4} (Lacy et al. 1994). For the kinematic distances, we used the Reid et al (2016) Bayesian approach, which includes priors based on Galactic arm signatures seen in CO and HI surveys. Cloud elongations were derived with the SCIMES ellipsoidal fit procedure (see Colombo et al. (2015). The histograms below display the total H_2 cloud mass, excitation temperature, and projected elongations distributions for the I_{ex} ThrUMMS clouds. The mean value of each distribution are shown by the black dashed line.



Filamentary Molecular Clouds

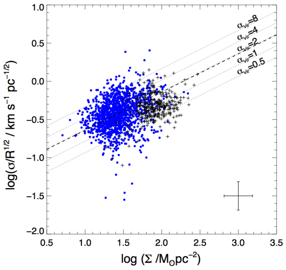
Molecular clouds with filamentary morphology are seen on parsec scale regions harboring proto-stellar activity (e.g., Myers 2009), as well as in their multi-parsec scale parent clouds (e.g., Ragan et al. 2014). We are in the process of compiling a molecular filament sub-catalog by visualizing the 2D projection of each cloud using ^{13}CO integrated intensity maps and P-V maps. Filament membership is based on its continuous structure, a minimum aspect ratio of 3, and a continuous and narrow linewidth (≤ 5 km s^{-1}). Below are a few examples of our filament candidates.

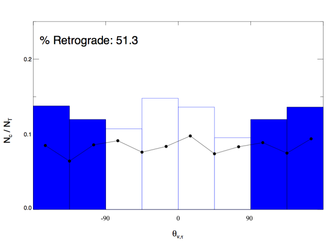


How do Star-Forming Filaments Form and Evolve?

To connect observationally derived properties of molecular clouds to star formation, we also need to understand how these clouds form and evolve. The virial parameter characterizes the dynamical state of a molecular cloud, i.e., a cloud undergoing global gravitational collapse versus dissipating into the diffuse ISM. We analyzed the dynamical state of all the I_{ex} clouds, finding the power-law relation $\sigma/R^{1/2} \propto \Sigma^n$ (e.g. Heyer et al. 2009) of n≈2.91±0.10 (left figure). These indices are larger than that expected for virialized clouds (n_{vir}=0.5). However, we find mean virial parameters of log(α)=0.29±0.52. If we force a power-law index of n=0.5, the mean virial parameters are log(α)=0.29 (black dashed line), suggesting that the whole population is nearly consistent with virial equilibrium. The error bar represents the estimated mean uncertainties of ~14% in $\sigma/R^{1/2}$ and 30% in Σ. The dotted lines represent the different scaling relation for virialized clouds with α_{vir}=0.5, 1, 2, 4, and 8.

Molecular clouds form stars with relatively low efficiencies. Hence, we must determine the lifetimes of the star-forming molecular filaments. Angular momentum implies that young clouds (~10^6 yr) should be pro-grade with respect to Galactic rotation, while longer-lived clouds (10^{7-8} yr) should under go cloud-cloud collisions leading to a randomization of rotation direction. The right figure shows the derived distribution of position angles of cloud angular momentum vectors with respect to the direction of Galactic rotation. We find a slightly larger fraction of ThrUMMS clouds with retrograde rotation (blue), suggesting that they have had time to interact with surrounding clouds and are therefore older than 10^6 years. The black line shows the results from the numerical simulation of Tasker & Tan (2009)





Selected References

Barnes, P.J., Muller, E., Indermuehle, B., O'Dougherty, S.N., Lowe, V., Cunningham, M., Hernandez, A.K., Fuller, G.,A., (2015) ApJ, 812, 6
Colombo, D., Rosolowsky, E., Ginsburg, A., Duarte-Cabral, A., & Hughes, A., (2015), MNRAS, 454, 2067
Reid M. J., Menten, K.M., Zheng, X.W., Brunthaler, A., Moscadelli, L., et al., 2009, ApJ, 700, 137

Acknowledgements

A.K.H acknowledges support from the National Science Foundation under grant AST-1517573. This work make use of ThrUMMS Survey and the SCIMES algorithm.