ThrUMMS: A New View of the Molecular Milky Way

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Abstract

We present the **Three-mm Ultimate Mopra Milky Way Survey**, a new mm-wave molecular-line mapping survey of the southern Galactic Plane, and its first data releases and science results. ThrUMMS maps a 60°×2° sector of our Galaxy's fourth quadrant, using a combination of fast mapping techniques with the Mopra radio telescope, simultaneously in the J = 1→0 lines of ^{12}CO, ^{13}CO, C^{18}O, and CN near 112 GHz, at 1′.2 and 0.3 km s^{-1} resolution, with 1.2 K/ch sensitivity for ^{12}CO and 0.7 K/ch for the other transitions. The calibrated data cubes from these observations are made freely available to the community on the ThrUMMS website, www.astro.ufl.edu/thrumms, after processing through our pipeline. Here, we showcase some sample data products and describe the first science results, on global variations in the iso-CO line ratios and on a detailed multiwavelength study of the GMCs near l=333°. The line ratios vary dramatically across the Galactic Plane, indicating a very wide range of optical depth and excitation conditions, from warm and translucent to cold and opaque. The population of cold clouds in particular have optical depths for ^{12}CO easily exceeding 100 in some locations, and suggests that the fraction of the molecular mass in the Galactic disk that is in the coldest gas may be substantially underestimated. We compute robust column densities from the global data and derive a new conversion law from CO to molecular mass, indicating that global relationships in disk galaxies that depend on the CO→H_2 mass conversion, such as star formation laws, may need to be recalibrated. Near l=333°, we have compared ThrUMMS data to HI, cm-continuum, and several *Herschel* and *Spitzer* bands to derive the overall mass and star formation properties of two complexes along the line of sight, in the Scutum-Centaurus and Norma arms. The RCW106 complex in particular is currently undergoing a ministarburst event, potentially shedding light on starburst physics in distant galaxies.

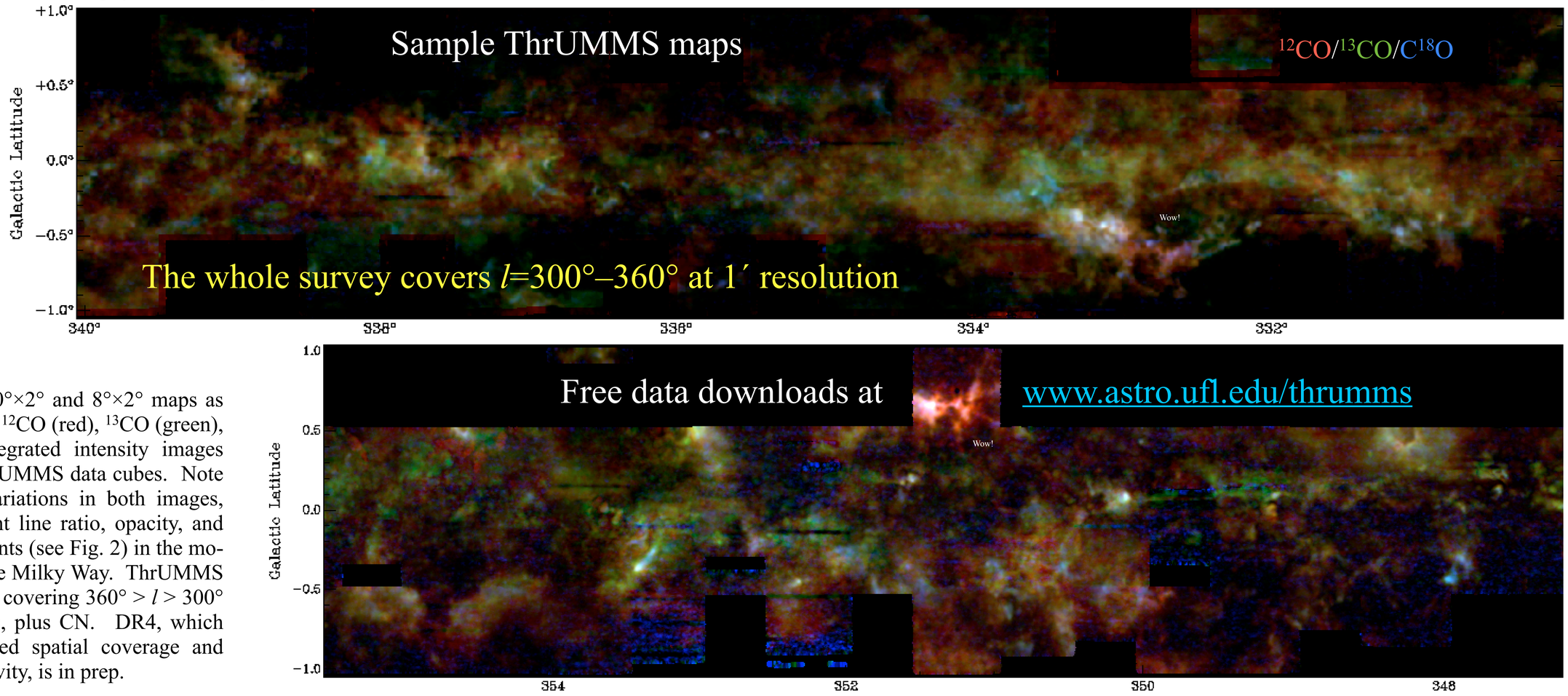


Figure 1: Sample 10°×2° and 8°×2° maps as colour composites of ^{12}CO (red), ^{13}CO (green), and C^{18}O (bue) integrated intensity images from DR3 of the ThrUMMS data cubes. Note the strong colour variations in both images, indicative of different line ratio, opacity, and excitation environments (see Fig. 2) in the molecular material of the Milky Way. ThrUMMS provides similar data covering 360° > l > 300° in all 3 iso-CO lines, plus CN. DR4, which will include improved spatial coverage and more uniform sensitivity, is in prep.

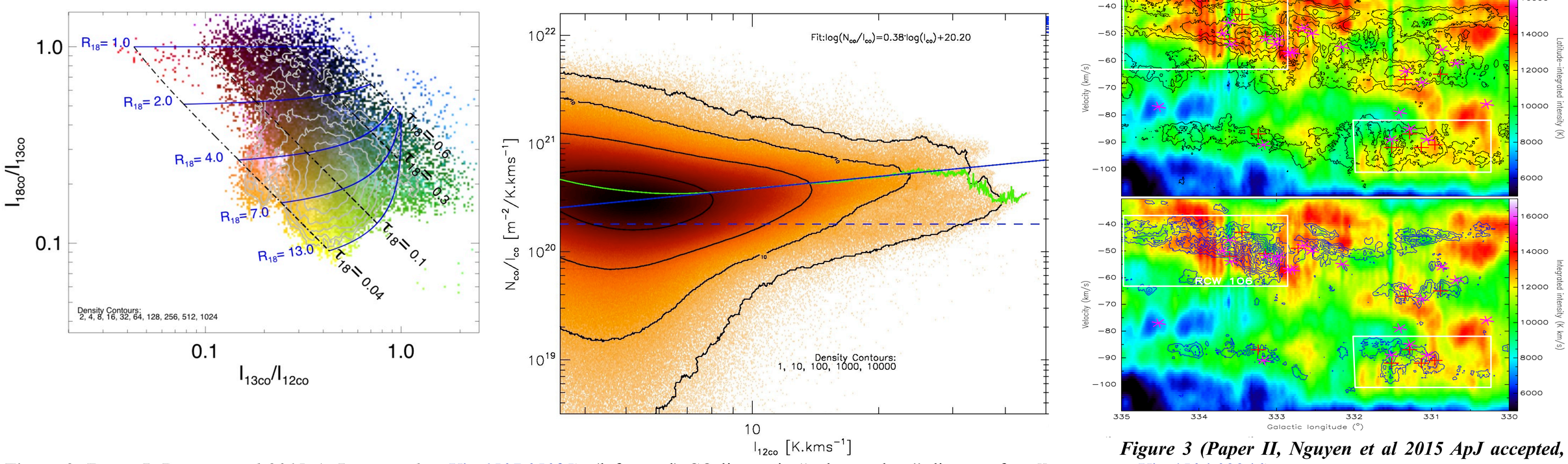
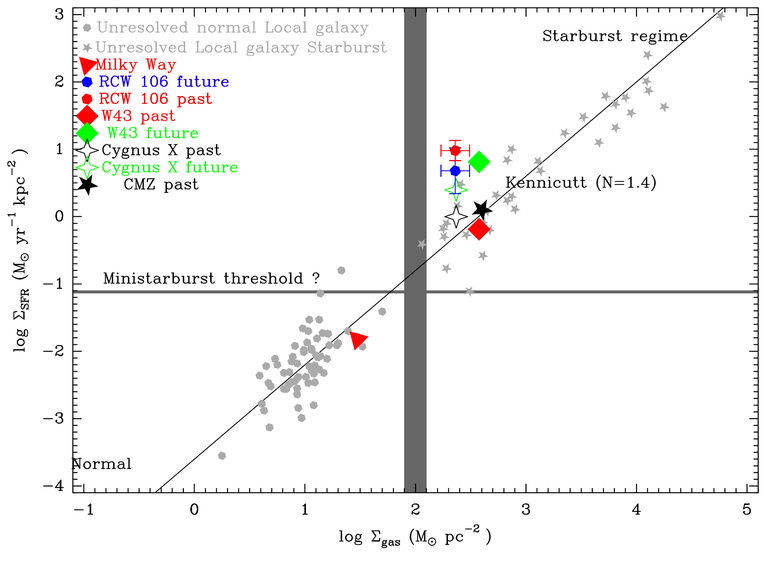


Figure 2 (Paper I, Barnes et al 2015 ApJ accepted, arXiv:1507.05095): (left panel) CO line ratio "colour-colour" diagram for **all ThrUMMS data** (~10^9 voxels!). The colours in this plot represent the relative line ratios as shown in the 3-colour image of Figure 1 (top of page). Overlaid here are radiative transfer models labelled by intrinsic ratio R_{18} = [^{13}CO]/[C^{18}O], and C^{18}O optical depth τ_{18}. This shows that there are many clouds in the Milky Way with previously unrecognised high optical depth, and consequently higher column density than suggested by the standard "X-factor" approach.

(right panel) Derived conversion from I_{CO} to N_{H2}, based only on the straightforward radiative transfer model. This is equivalent to a nonlinear conversion law, **$N_{CO} = 1.6\times10^{20}$ mol m^{-2} (I_{CO}/K km s^{-1})$^{1.38}$** and suggests that the molecular mass of the Milky Way may have been substantially underestimated.

Figure 3 (Paper II, Nguyen et al 2015 ApJ accepted, arXiv:1504.02246): (above) Longitude-velocity diagrams of HI (colour image), overlaid by ThrUMMS ^{12}CO (top panel, black contours) and ^{13}CO (bottom panel, blue contours). HI absorption against the brightest HI emission results in vertical bands of relatively low (green) net HI emission cutting through higher intensity (yellow, red) regions for the entire velocity range corresponding to foreground gas.

(below) Schmidt–Kennicutt relation between star formation rate (SFR) density and gas surface density, from normal spiral galaxies to starbursts. Points for the RCW 106 complex and other Milky Way locations suggest that RCW 106 is the most vigorous star formation complex in the entire Galaxy.



Pending Applications

ThrUMMS' legacy value will be enormous, and will generate a large number of follow-up studies, e.g.:

- Excitation studies with companion SEDIGISM survey (PI: Schuller), of J = 2→1 lines of ^{13}CO and C^{18}O using APEX
- Spatially-resolved gas temperature maps of GMCs, & comparison with *Herschel*-based SED fits/dust temperatures
- Detailed structural & kinematic comparisons with *Herschel* data and the GASKAP HI survey, studies of molecular cloud formation
- Kinematic distances of all major ISM structures from a ThrUMMS+GASKAP comparison
- Statistics-based analysis of Galactic structure on wide and small scales
- Detailed dynamics of Galactic-scale features
- Arm-interarm comparisons, radio-FIR correlation
- Spatial dependence of cloud turbulence, origin of turbulence
- Unbiased catalogue of all CN-bright clouds, suitable for Zeeman measurements with ALMA
- Dependence of astrochemistry, cloud structure, and kinematics on Galactocentric distance and other environmental factors