ThrUMMS

The Three-mm Ultimate Mopra Milkyway Survey

Composite ^{12}CO ^{13}CO C^{18}O image around the G333 complex, from DR6.

Data Release User's Guide

ThrUMMS is a multi-species survey of molecular clouds and star formation across much of the Fourth Quadrant (4Q) of the Milky Way, $360° > l > 300°$ and $-1° < b < +1°$. The Data Releases are available at the ThrUMMS DR Bank (DRB) and the NASA/IPAC IR Science Archive. The primary references for the DRs, including observational and analytical details, are given below. If you find these data useful for your research, please cite the appropriate paper as listed, available from the ThrUMMS Bibliography or standard ADS queries. If your work makes *significant* use of these data, **ThrUMMS policy** is to include at least one of our team as collaborators or co-authors (contact email below).

The data consist of 3D data cubes of the *J* or *N*=1–0 emission (~110 GHz) from the molecules ^{12}CO, ^{13}CO, C^{18}O, and CN, plus a selection of 2D moments (integrals) of these cubes. While the survey covers $60° \times 2°$ on the sky, the data cubes are very large and therefore broken up into ten $6° \times 2°$ "Sectors" (each up to ~1 Gb) in order to make downloads and file management more practical. The 2D moment maps are only ~1–10 Mb and so cover the full $l \times b$ (*V*-moments) or $l \times V$ (*b*-moments) extent of the survey. The data pixels or voxels are of size 24″ (*l* or *b*) and ~0.34 km/s (V_{LSR}; this varies slightly with the species), so the survey dimensions are approximately 9000 pixels in *l* (900/Sector), 300 pixels in *b*, and up to 1000 channels in V_{LSR}, depending on the Sector and species (but see below). A full (l,b,V) cube for one species would therefore contain 2.7×10^9 voxels and have filesize ~5 Gb.

The 2D+3D gzipped FITS files can be previewed within the IRSA pages, and downloaded & viewed with a wide range of software packages. We recommend *kvis*, part of the Karma package (Gooch R.E. 1996, "Karma: a Visualisation Test-Bed," in *Astronomical Data Analysis Software and Systems V*, ASP Conf. Series **101**, ed. G.H. Jacoby & J. Barnes, ASP, San Francisco, pp80-83, ISSN 1080-7926), for its (l,b,V)-friendly display tools.

NOTE: the IRSA preview of the 3D cubes defaults to the central channel in each cube, which doesn't necessarily correspond to the brightest emission. The 2D moments *do* cover all detectable 4Q emission, but to see the full 3D emission patterns, one should view the appropriate channels. The standard ThrUMMS Sector cubes cover a typical velocity range -150 km/s $< V_{\mathrm{LSR}}$ $< +50$ km/s but this varies somewhat by Sector, as noted in the DRB webpage. Again, *kvis* makes it easy to view such cubes.

Alternative data products. For some science needs, slightly different data products may be desirable. For example, the native velocity resolution of the 4096-channel Mopra spectrometer is ~0.085 km/s: the available DR6 Sector cubes are actually 4-channel-binned versions of the native data cubes, which are consequently $>4\times$ larger (due also to truncation of the DR6 cubes at extreme V_{LSR}) than the sizes indicated on the DRB (but then also, with $2\times$ the per-channel noise), $>10^{10}$ voxels or >20 Gb filesize per species. Or, cubes that have been binned by 12 channels (to

~1 km/s per channel) might also be useful, in which case a single full-sky file could be <2 Gb in size. Other examples might be for custom cutouts in (l,b,V)-space with SAMed moments. In all such cases, collaborative arrangements for such products would be welcomed; we already have extensive processing and analysis tools that can readily assemble most such options.

We describe some notable features of each DR below.

DR1 (from 2011):

This contains the first small mosaics of multiple 0.5°-square on-the-fly maps (single Mopra raw data files), some up to 2°×0.5°, but all within a strip –0.5° < b < 0.0°.

DR2 (2012):

Latitude coverage doubled to $|b|$ < 0.5° and all DR2 cubes ("Regions") are of size $l{\times}b$ = 2°×1°, each conjoining 8 OTF maps. Together they cover nearly all of the survey's 60°.

DR3 (observing 2013–15; some data available 2014):

References: Barnes, Muller, Indermühle, et al 2015, *ApJ*, **812**, 6 (Paper I)
Nguyen, Nguyen-Luong, Martin, et al 2015, *ApJ*, **812**, 7 (Paper II)

The objective was to double the latitude coverage to $|b|$ < 1°, but also to reobserve DR1–2 OTF maps that were affected by bad weather, and similarly for DR3 data, and reprocess all data to remove instrumental artifacts ("the pox"). The DR3 files were the first to be organised into 6°×2° Sectors, conjoining up to 48 contiguous OTF maps, and the number of fully-sampled DR3 Sectors publicly available (primarily for ^{12}CO and ^{13}CO; work on the C^{18}O and CN data was more patchy) gradually increased during this period, as observing and data reduction proceeded.

DR4 (2016):

After observing was completed, processing beyond the DR3 quality level was initially focused on ^{13}CO only. DR4 aimed to remove the last remaining "weather stripes" from all data products. The full ^{13}CO coverage made available in DR4 represented the first step in this effort.

DR5 (2017):

Raising the quality level of data products for the other 3 species (no pox or weather stripes) was the main focus of DR5. This was enabled by short-term access to significant National Astronomical Observatory of Japan (NAOJ) computing resources, and was available for about a year on the NAOJ servers. Unfortunately, DR5 was lost after our access expired. Work to recover an equivalent to DR5 continued intermittently over the next few years, without funding support.

DR6 (2025 March):

Reference: Barnes et al 2025, *ApJS*, submitted (Paper III), arXiv:2503.04887

NSF stepped into the breach in late 2022, and we redid the de-poxing and de-striping for ^{12}CO and C^{18}O. Together with the prior work on ^{13}CO, this comprised part of the new DR6. The CN data remains unprocessed beyond the patchy DR1–3 coverage as described above (see also the DRB page).

Moment Maps: For the first time in DR6, we also constructed several 2D moment maps using the SAM algorithm, for each of the 3 iso-CO species. These include the integrated intensity I (zeroth moment) and its error map, the intensity-weighted mean velocity (first moment) and velocity dispersion (second moment), the per-channel T_r^*-rms map, and the b-integrated lV map, for a total of 18 2D FITS maps.

Future Data Releases: DR7, 8, … etc.

More data cubes and moment maps, such as each molecular species' excitation temperature, opacity, column density, and gas-phase abundance, are planned for future releases. If researchers wish to obtain pre-release access to these data products for their own projects, or suggest others for future development, they may be available by collaborative arrangement. Please contact the PI of ThrUMMS, Peter Barnes (pbarnes@spacescience.org) to inquire.