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LMTOY: The LMT Single Dish Spectral Line Toolkit

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Abstract. With the goal of adding Science Ready Data Products to the archive of the Large Millimeter Telescope (LMT), we have developed a toolkit that allows automated pipeline processing of LMT single dish spectral line data. The data products include automatic source detection and spectral line detection using the ALMA Data Mining Toolkit (ADMIT). Adopting SDFITS as the interchange format, we aim that other observatories can use our toolkit and that LMT data can be analyzed by other packages. Interoperability tests are planned for this. In addition to the on-site Quick Look products, we now produce Timely Analysis Products (TAP) within 15 minutes after the observation has ended for an on-the-fly map, and much faster for pointed observations. These provide the scientist with rapid feedback on the scientific content.

1. Introduction

As for so many observatories, the Large Millimeter Telescope (LMT)[1] experienced a prolonged shut-down during the COVID-19 pandemic, but in late 2021 resumed taking data. This included the commissioning of two new continuum instruments: TolTec and MUSCAT. We took this opportunity to refactor the existing spectral line code into a more uniform pipeline[2], covering at least three current instruments (SEQUOIA, Redshift Search Receiver, MSIP 1mm receiver), and planning a future fourth instrument (Omaya).

Traditionally the back-end of the instrument would dictate the data reduction software, and for a PI this can be frustrating to have to learn several software systems. All instruments share the same telescope control system, and all raw data have been written in netCDF (version 3) format[3], but what happens after that depends on the instrument.

[1]http://lmtgtm.org/

[2]LMTOY: https://github.com/astroumd/lmtoy

[3]An exception is the B4R receiver with its own in-house software, XFFTS, but has a path to convert to netCDF

The first (pre-pandemic) data, on M51, processed with the new LMTOY pipeline, were published in Heyer et al. (2022). Figure 1 shows the measured gas distribution in two molecular lines.

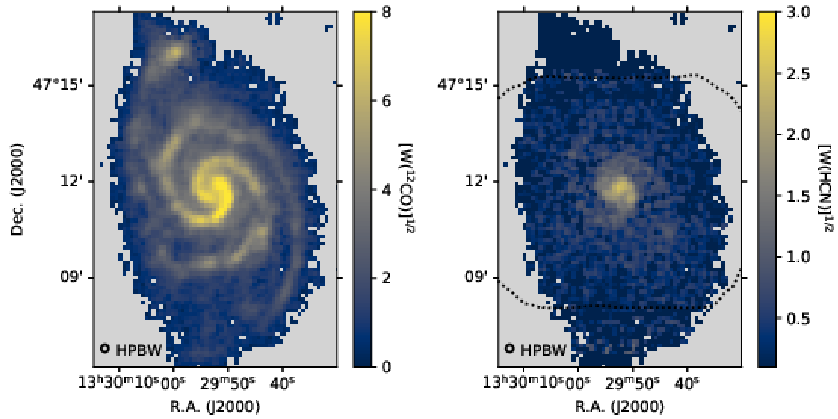


Figure 1. Total amount of CO gas (left) and HCN (right) as obtained with the 16 beam Seqouia receiver in on-the-fly (OTF) mode.

2. Instruments

A variety of instruments and receivers can be deployed at the LMT: from single pixel to multi-beam pixels, and in spectral line and continuum mode. We only discuss spectral line here.

3. SDFITS

Although the LMT stores RAW data in netCDF, a natural interchange format for single dish data is the SDFITS (Garwood 2000; Jenness et al. 2015) format[4], which would apply to what we currently call the *specfile* format. This is the format where all spectra are calibrated, and the only thing left is gridding. A number of multi-beam instruments use the MBFITS format, but this is mostly for their RAW storage. Another popular single dish format is the one used by CLASS. GBTIDL uses the SDFITS format, in particular their new gridder should be able to handle LMT data as well, and vice versa, which would be a good opportunity for interchange tests.

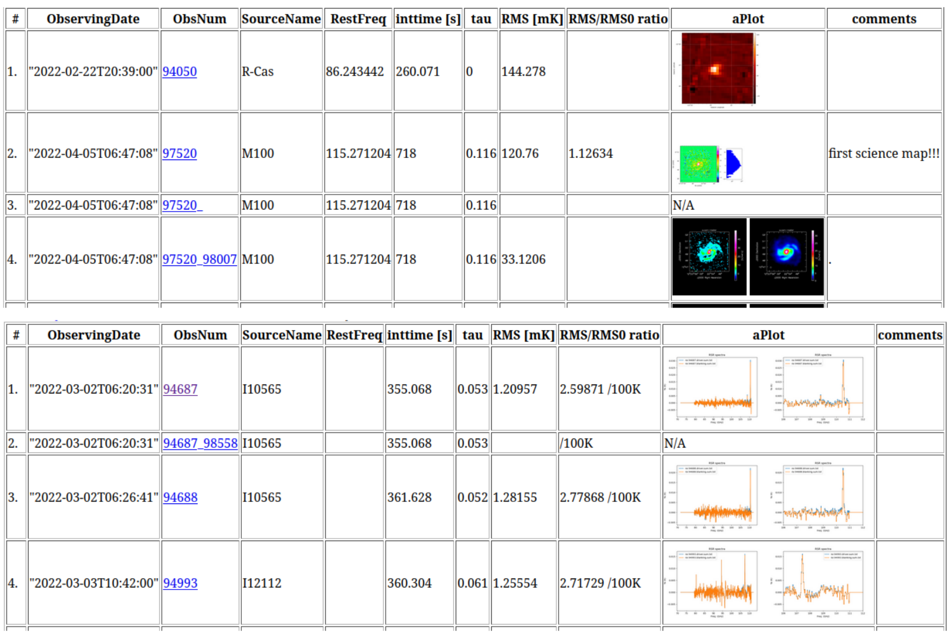
4. Pipeline vs. Toolkit

There are two competing effects we addressed in the design. On the one hand, the there is a need for a flexible toolkit for interactive processing. For example we have

[4]Jenness et al. talk about GSDD, the General Single Dish Data Format

a few Jupyter Notebooks that illustrate the steps necessary to construct a final spectral line data cube from the raw data. On the other hand, an efficient pipeline needs to run automatically with no human interaction. Our current pipeline is written in `bash`, calling our own LMT python modules as well as numpy/scipy, standard Unix software (e.g., ImageMagick) and some 3rd party software such as NEMO (Teuben 1995).

Single dish observations are often taken as a large series of short observation (called an ObsNum at LMT), which are individually inspected, and stacked (and/or gridded) where the data quality allows. The pipeline products are presented to the user as a Timely Analysis Product, in the form of a summary table (see Figure 2). These data can be viewed within 15 minutes after the data have been taken, from which data products can optionally be downloaded. After all observations have been obtained and checked and stacked, a final combined dataset is produced by the same pipeline.



#	ObservingDate	ObsNum	SourceName	RestFreq	inttime [s]	tau	RMS [mK]	RMS/RMS0 ratio	aPlot	comments
1.	"2022-02-22T20:39:00"	94050	R-Cas	86.243442	260.071	0	144.278			
2.	"2022-04-05T06:47:08"	97520	M100	115.271204	718	0.116	120.76	1.12634		first science map!!!
3.	"2022-04-05T06:47:08"	97520_	M100	115.271204	718	0.116			N/A	
4.	"2022-04-05T06:47:08"	97520_98007	M100	115.271204	718	0.116	33.1206			.

#	ObservingDate	ObsNum	SourceName	RestFreq	inttime [s]	tau	RMS [mK]	RMS/RMS0 ratio	aPlot	comments
1.	"2022-03-02T06:20:31"	94687	I10565		355.068	0.053	1.20957	2.59871 /100K		
2.	"2022-03-02T06:20:31"	94687_98558	I10565		355.068	0.053		/100K	N/A	
3.	"2022-03-02T06:26:41"	94688	I10565		361.628	0.052	1.28155	2.77868 /100K		
4.	"2022-03-03T10:42:00"	94993	I12112		360.304	0.061	1.25554	2.71729 /100K		

Figure 2. Example section of the summary table of the Timely Analysis Products (TAP) for Sequoia (top) and RSR (bottom). This will be the landing page where the PI can assess the data quality, and from where data can be downloaded before it has been archived at DataVerse.

5. Gridding

For OTF observations, an additional gridder is needed to resample and coadd data to the desired pixel size and angular resolution (Mangum et al. 2007). Our existing gridder was written in C, and sufficed in performance for typical LMT data. Other gridders exist in the community, which generally use SDFITS as the input format.

6. ADMIT

Fully calibrated data cubes (or spectra) are processed by ADMIT (Teuben et al. 2015) and deliver a set of Scientific Data Products to the archive. This includes line detections, moment maps, position-velocity maps, etc.

7. Archive

We have adopted DataVerse[5] to archive LMT data, and are in the process of adding a number of IVOA interfaces, such as ConeSearch, SIAP and SSAP. Although final stacked data products will be available as soon as all data have been processed by the pipeline, final archiving will occur on a longer timescale, when quality has been assured.

8. Code and Documentation

Documentation is maintained using sphinx, but still very fluid. During development this is maintained here: https://www.astro.umd.edu/~teuben/LMT/lmtoy/html/. We expect version 1.0 of the pipeline to be operable in the Fall of 2022.

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References

Garwood, R. W. 2000, in Astronomical Data Analysis Software and Systems IX, edited by N. Manset, C. Veillet, & D. Crabtree, vol. 216 of Astronomical Society of the Pacific Conference Series, 243

Heyer, M., et al. 2022, ApJ, 930, 170. 2204.09613

Jenness, T., et al. 2015, Astronomy and Computing, 12, 162. 1506.03136

Mangum, J. G., et al. 2007, A&A, 474, 679. 0709.0553

Teuben, P. 1995, in Astronomical Data Analysis Software and Systems IV, edited by R. A. Shaw, H. E. Payne, & J. J. E. Hayes, vol. 77 of Astronomical Society of the Pacific Conference Series, 398

Teuben, P., et al. 2015, in Astronomical Data Analysis Software an Systems XXIV (ADASS XXIV), edited by A. R. Taylor, & E. Rosolowsky, vol. 495 of Astronomical Society of the Pacific Conference Series, 305

[5] https://dataverse.org/