SF2A 2013
L. Cambrésy, F. Martins, E. Nuss and A. Palacios (eds)

THE M33 CO(2-1) SURVEY - STAR FORMATION AND MOLECULAR CLOUDS FORMATION

C. Druard[1, 2], J. Braine[1,2] and K. F. Schuster[3]

Abstract. The IRAM Large Program consisting of observing the CO(2-1) transition in the Triangulum galaxy M33 is now over. This very sensitive survey covered the disk of the galaxy up to 8 kpc. Here we present the results and the techniques used in the data reduction process as well as the integrated intensity map. We determined that the velocity dispersion between molecular and atomic gas is very low. Whith this dataset, molecular cloud detection algorithm were also able to found more than 500 giant molecular clouds.

Keywords: galaxies, Local Group, ISM, molecular clouds, star formation

1 The observation of M33

The Triangulum galaxy, M33, is one of the closest spiral galaxies (840 kpc). With a mass of ∼10% of the Milky Way, M33 provides a stepping-stone between large spirals and smaller irregular galaxies like the Magellanic clouds. With its half-solar metallicity, gas-rich medium, and young stellar population, M33 is an ideal step towards younger and lower metallicity objects. Its proximity and optimal inclination allow us to study its molecular gas content, in terms of global/local dynamics and of giant molecular clouds and star formation. M33 has been observed at many FIR wavelengths in the framework of the Herschel HerM33es key project. We also dispose of a large amount of data at many different wavelength (UV, X, HI ...).

We have now completed the IRAM M33 large program of very sensitive 230GHz CO(J=2-1) observations covering the optical disk (figure 1) with a 12" spatial resolution (∼50pc) allowing us to detect ∼500 clouds. The observations were done using the 30-meter telescope of the Institut de RadioAstronomie Millimtrique (IRAM) on Pico Veleta in Spain. This work is a follow-up to Gardan et al. (2007) and Gratier et al. (2010) with a partial coverage of the disk. M33 was observed with the multi-pixel receiver HERA Schuster et al. (2004) using On-The-Fly mapping technique which enhance the mapping speed. The main goals of this Large Program are to identify the Giant Molecular Clouds (GMCs) and study their evolution.

2 Data processing

After 5 years of observations we obtained up to 2.10^8 spectra in about 400 hours in a field of view of 55'x400' which accounts for about 400Go of raw data. Data reduction was done using the IRAM GILDAS reduction packages CLASS and GREG. The difficulty was to optimize the reduction process while staying consistent whith the previous works of Gardan et al. (2007) and Gratier et al. (2010). This process can be summarized into these following steps:

1. at first we eliminate poor data
2. we cut every spectra from -500 km/s to 0 km/s velocity shift, corresponding to M33 velocity range
3. we fit a 0 order baseline to get rid of the continuum in each spectrum

[1] Univ. Bordeaux, LAB, UMR 5804, F-33270, Floirac, France
[2] CNRS, LAB, UMR 5804, F-33270, Floirac, France
[3] IRAM, 300 rue de la Piscine, 38406 St. Martin dHères, France

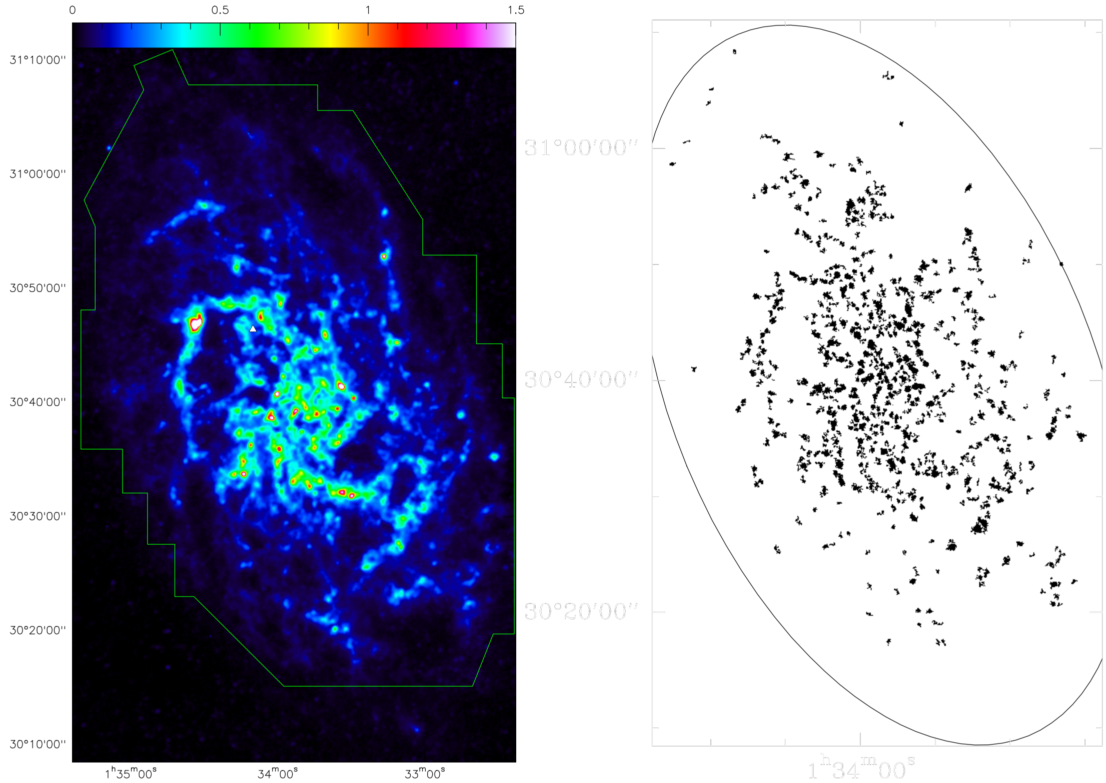

Fig. 1. Left: The Triangulum galaxy M33. This image shows the full coverage of the CO(2-1) mapped field with the edges in yellow on top of a Herschel 250m UV data that traces hot dust. **Right:** Molecular clouds detected in M33 with the CPROPS algorithm.

4. we compare the RMS noise of each spectrum with the theoretical noise given by the radiometer equation $\sigma_{theo} = 2\frac{T_{sys}}{\sqrt{\Delta_\nu t}}$ (where T_{sys} is the system temperature, Δ_ν the channel width and t the integration time of the spectrum). The spectra presenting a RMS noise higher tha $1.1\sigma_{theo}$ are filtered out ($\sim$ 11% of the dataset)

5. since each position in M33 is associated with more than one spectra, we build a datacube (3D position-position-velocity map)and then convert it back to regularly gridded spectra with higher signal to noise ratio than the previous ones.

6. we fit a third order polynomial baseline on each spectra. This time we use velocity-windows inside which the signal is excluded from the fit. For this we use HI 25"x25"x1.27km/s VLA maps from Gratier et al. (2010), making the assumption that the molecular gas cannot be present at positions and velocities where there is no atomic gas. The limits of these windows are computed with the following technique: we detect HI higher than 4σ (10K) in the HI datacube and then we go down on each side of the HI peak to the first channel at or below 0K that gives us the corresponding velocity associated with the upper or lower limit. For areas where there is no HI detected, window limits are given by the rotation curve given in Corbelli & Schneider (1997) $\pm$30km/s.

7. we build a last cube with a spectral resolution of 2.6km/s and a spatial resolution of 12"

We obtain a data-cube with a relatively homogeneous RMS noise of 20mK as seen in figure 2.

3 First results

3.1 *Integrated intensity m*

Integrated intensity maps were also produced using the same masking techniques than during the reduction process. Only the channels corresponding to velocities associated with HI emission were used to compute these maps. This adaptive fit technique ensures the map not to contain too much noise and, at the same time, increase the sensitivity to diffuse CO emission. The obtained map is shown in figure 2. We can see that, apart from diffuse emission, the CO is located in the first kiloparsecs of the disk and regroup into clouds.

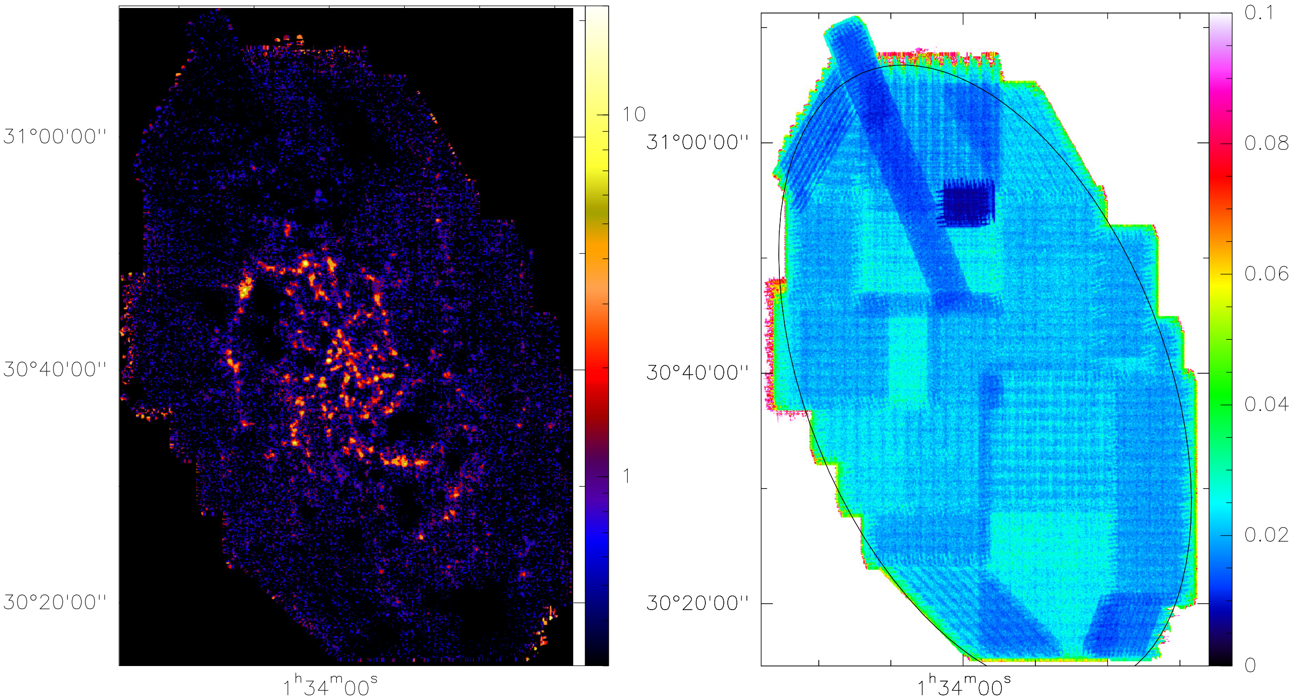

Fig. 2. Left: Integrated intensity map of the CO(2-1) line in K.km/s. Combination of HI-0K mask and rotation curve mask (where there is no HI detected) was used to compute this map.. **Right:** RMS noise map of M33 in Kelvin. The black ellipse corresponds to a distance of 7kpc from the center.

3.2 Centered cube

Comparisons with the HI emission shows that the CO-HI velocity dispersion is extremely low. A useful technique to "better see" the CO emission is to stack every spectra around the velocity of the HI peak since weak CO emission cannot be seen in singular spectra. To do this we produced recentered data-cubes : each CO spectrum is centered at a reference velocity corresponding to the HI peak velocity at this position in the sky. With this new data-cube we were able to stack the signal in larger areas where the CO peak velocity were not previously homogeneous. We produced stacked spectra corresponding to HI-free areas to verify our first hypothesis of no CO at positions and velocities different from HI. The produced stacked spectra were indeed consistent with the signal that we would obtain from error beam pickups of the 30m telescope. The stacked spectra corresponding to the whole disk show a very narrow velocity dispersion on the global scale of ∼11km/s, which means that CO follows well the HI in terms of position and velocities.

3.3 Molecular clouds detection

The CO emission has been decomposed into clouds using the CPROPS detection algorithm (Rosolowsky et al. 2007) which also computes properties associated to each detected GMC. At this distance, we are able to resolve GMCs down to the size of 50pc. More than 500 GMCs were detected whithin this new dataset compared to the 337 clouds detected by Gratier et al. (2012) with half the disk coverage and we found that the linewidth of these clouds is smaller for a given size than in the Milky Way. This cloud sample is the largest up to date in an external galaxy. Figure 1 shows the repartition of these clouds which total mass is about 1.8 $10^8 M_\odot$ which is coherent with previous studies and can be compared with 3.3 $10^8 M_\odot$, which is the total mass of M33 computed from the whole CO(2-1) emission. We intend to use this sample to characterize each clouds in terms of star forming activity using tracers like Hα, FUV, 24μm. This sample will also be useful to understand the formation conditions of these clouds, study their distribution on the disk, the evolution of some parameters with the position or the radial distance and understand better the conditions of formation of these GMC in subsolar metallicity environment.

References

Corbelli, E. & Schneider, S. E. 1997, ApJ, 479, 244

Gardan, E., Braine, J., Schuster, K. F., Brouillet, N., & Sievers, A. 2007, A&A, 473, 91

Gratier, P., Braine, J., Rodriguez-Fernandez, N. J., et al. 2012, A&A, 542, A108

Gratier, P., Braine, J., Rodriguez-Fernandez, N. J., et al. 2010, A&A, 522

Rosolowsky, E., Keto, E., Matsushita, S., & Willner, S. P. 2007, ApJ, 661, 830

Schuster, K.-F., Boucher, C., Brunswig, W., et al. 2004, A&A, 423, 1171