Observations of giant molecular clouds in Nearby Galaxies with ALMA

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Star formation processes: currently open questions

- Nearby galaxies
- The galactic GMC W49
- Simulations of ALMA observations
Some still open questions about star formation in galaxies:

- Importance of local (disk or cloud instability) versus global effects (spiral density waves, tidal forces, magnetic fields) in triggering SF.

- How the properties of SF depend on various environmental parameters.

- How SF might differ in nuclear regions or in burst and quiescent modes.

- Which is the role of the relativistic phase (cosmic rays and magnetic field) in SF processes.

- Do giant molecular clouds care about the galactic structure?
Evidence of GMCs sensitive to their galactic environments
In very nearby galaxies: M51, M33, SMC

(Hughes et al. 2013)
Nearby galaxies

NGC3627 @ 11 Mpc

CO(1-0) image (BIMA)
Resolution ~ 6 arcsec ~ 320 pc

Helfer et al., 2003

CO(1-0) image (IRAM)
1.4 GHz contours (VLA)
Resolution ~ 2 arcsec ~ 100 pc

Paladino et al., 2008

Typical size of a GMC in the Milky Way is 40 pc...
Nearby galaxies

We need:

- high spatial resolution to resolve different components
- high spectral resolution to avoid blendings of regions with different velocities

NVSS 1.4 GHz image of the W49 complex
ALMA resolution

<table>
<thead>
<tr>
<th>Band</th>
<th>Freq GHz</th>
<th>FoV arcsec</th>
<th>min res arcsec</th>
<th>max res arcsec</th>
<th>Scale @ 10 Mpc (pc)</th>
<th>50 Mpc (pc)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>31.3 - 45</td>
<td>145 - 135</td>
<td>13 - 9</td>
<td>0.14 - 0.1</td>
<td>5</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>67 - 90</td>
<td>91 - 68</td>
<td>6 - 4.5</td>
<td>0.07 - 0.05</td>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>84 - 116</td>
<td>72 - 52</td>
<td>44.9 - 3.6</td>
<td>0.05 - 0.038</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>125 - 163</td>
<td>49 - 37</td>
<td>3.3 - 2.5</td>
<td>0.035 - 0.027</td>
<td>1.3</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>211-275</td>
<td>29-22</td>
<td>2.0 - 11.1</td>
<td>0.021 - 0.016</td>
<td>0.77</td>
<td>5</td>
</tr>
</tbody>
</table>

Not yet available
In Band 2 DCO$^+$ (1-0); DCN and NH$_2$D predicted from simulations in starburst or CR enhanced regions (Bayet 2010)

CO(1-0); HCN(1-0); HCO$^+$ (1-0)

DCO+ (2-1)

CO (2-1); HCN (3-2); HCO+ (3-2); SO$_2$
The galactic GMC W49

One of the most luminous star forming regions in the MW @ ~11 kpc
$L \sim 10^{7.2} L_\odot$ (Sievers et al. 1991) $M_{\text{gas}} \sim 10^6 M_\odot$ (Miyawaki et al., 2009)

MUSCLE W49
Lines and continuum observations in 4 GHz bands
@ 220 and 230 GHz
resolution: 2 arcsec to 0.8 arcsec
More than 50 molecules (isotopologues) Have been identified.

CO(2-1) integrated flux
$1.23553 \times 10^5$ Jy km s$^{-1}$
$rms = 4.8$ Jy beam$^{-1}$ km s$^{-1}$

Galván-Madrid et al., 2014
The galactic GMC W49

Comparison between thermal free-free and molecular emission

**W49A**
CO(2-1) SMA image
Contours 3.6 cm free free emission

**W49A zoomed-in**
CO(2-1) SMA image
Contours 3.6 cm free free emission

Galván-Madrid et al., 2014
The galactic GMC W49

Channel map
The galactic GMC W49

Integrated intensity map

Region size ~ 2.5' → ~ 8 pc

Peak = 12.85 Jy
Freq resolution = 1.2 km/s

Velocity intensity map
Scaling the peak brightness, the observing frequency, and the channel width of W49A at various distances, observations with ALMA in Band 6 at resolution of 0.03'', 5 min on source (rms ~ 3 mJy/beam) have been simulated.

Size
~2.5''
~0.5''
~0.25''

Spatial res (pc) 0.11 0.72 1.45

Peak (Jy km/s) 1.2 0.6 0.45
Simulations of ALMA observations

**W49 @ 30 Mpc**

Observation 30min on source (rms ~ 1mJy/beam)
Spatial res ~ 4 pc

The CO line profile of the cloud is well visible even when the structure is unresolved.
Simulations of observations with ALMA show how a GMC like the galactic W49A can be seen in galaxies up to 30 Mpc. The study of a large sample of GMCs in nearby galaxies can help in understanding star formation processes.