Physical conditions and structure of the ISM in nearby low-metallicity star-forming galaxies

Diane Cormier
ITA, University of Heidelberg
Laboratoire AIM, CEA Saclay

Suzanne Madden, Katja Fahrion, Alexandros Dimaratos, Vianney Lebouteiller, Sacha Hony, Nick Abel, Fiorella Polles and collaborators
Cold ISM difficult to observe

Little molecular gas traced by CO


ALMA at $Z=1/30$ solar and 0.2″=50pc resolution

Cormier et al. subm.
Motivation: recent access to ISM tracers

What are the properties of the environment (large-scale ISM) in which stars form?

IC10
D=700 kpc
Z=0.3 solar

Poster of Fiorella Polles

- FIR lines tracing PDRs now detected in many low-metallicity galaxies

Polles+ in prep.
Tracers of the ISM conditions

**Tools:** *Herschel, Spitzer* and optical observations
+ Cloudy spectral synthesis models

**ISM diagnostics:**

- **HII**
  - \([\text{SIII}]18/33 \Rightarrow \text{electron density}\)
  - \([\text{NeIII}]/[\text{NeII}]\)
  - \([\text{SIV}]/[\text{SIII}]18 \Rightarrow \text{radiation field}\)
  - \([\text{OIII}]/[\text{NII}]\)

- **PDR**
  - \([\text{OI}]/[\text{CII}]\)
  - \([\text{OI}]/L(TIR) \Rightarrow \text{temperature, density}\)
  - \([\text{OI}]63/145\)
  - \([\text{CII}]/\text{CO} \Rightarrow A_V\)

+ Constrain masses and filling factors of the main phases
Modeling: strategy

**Cloudy**
*Abel et al. 2005, Ferland et al. 2013*

**Starburst99**
*Leitherer et al. 2010*

Model grid setting:

- **Instantaneous SF**
- **Abundances varied with Z**
- **Stopped at A_v = 10 mag**
- **Pressure equilibrium**

Five bins of Z [0.05, 0.1, 0.25, 0.5, 1]

Grids varying: \( n_H, U, t_{burst} \)

Strategy: *(30 galaxies from the Herschel Dwarf Galaxy Survey)*

1) Derive best-fitting model for HII region
2) Predict PDR phase

*Cormier et al. 2015*
*Cormier et al. in prep*
Haro3

- Results over sample:
  \[ \log n_H = 2.2 \ \text{cm}^{-3} \ [2.7] \]
  \[ \log U = -2 \ [-3] \]
  \[ t_{\text{burst}} = 3 \ \text{Myr} \]

\[ \text{Hard radiation fields} \]
\[ \text{Larger HII regions} \]

Cormier et al. in prep
Results over sample:
\[ \log n_H = 3.5 \ \text{cm}^{-3} \]  
\[ \log G_0 = 2.5 \]  
\[ [3.5] \]  
\[ [3] \]  

Moderate \( G_0 \): PDRs further away from stellar source  

Cormier et al. in prep
[CII]/CO ratio and PDR structure

- High [CII]/CO ratios observed in star-forming dwarf galaxies

What is this telling us about the molecular cloud/PDR structure?

Figure adapted from:
Madden 2000,
Stacey et al. 2010
Hailey-Dunsheath et al. 2010
Modeling: the [CII]/CO ratio determines $A_V$

- Average depth of the clouds lower
CO-dark gas dominates the molecular mass budget

- [CII]/CO as a new tool
- ALMA CO, CI follow-ups for robust calibration

Madden+ 2016
Madden+ in prep.
Low-metallicity ISM properties: result of evolution or intrinsically different?

NGC4214: close-up view on separate regions

D = 2.9 Mpc
Z = 1/3 solar
SFR = 0.1 M☉/yr

Region I
SSC 3-5Myr
more evolved and diffuse

Region II
OB associations 2Myr
Younger and more compact

PACS [CII] map
CO(1-0) contours
GREAT: 5 pointings

U, B band
Hα+[NII]
[OIII]

Ubeda et al. 2007
Mackenty et al. 2000
NGC4214: C+ associated with the dense phase?

PACS [CII] map
CO(1-0) contours
GREAT: 5 pointings

<table>
<thead>
<tr>
<th>Region</th>
<th>Region I</th>
<th>Region II</th>
<th>Region III</th>
</tr>
</thead>
<tbody>
<tr>
<td>I(CII) attributed to CO</td>
<td>75%</td>
<td>55%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Fahrion+ 2016
NGC4214: effects of evolution

PACS [CII] map
CO(1-0) contours
GREAT: 5 pointings

<table>
<thead>
<tr>
<th>Region</th>
<th>CII attributed to CO</th>
<th>CO-dark H₂ mass</th>
<th>Covering factor</th>
<th>D(PDR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region I</td>
<td>75%</td>
<td>80%</td>
<td>1/3</td>
<td>170pc</td>
</tr>
<tr>
<td>Region II</td>
<td>55%</td>
<td>65%</td>
<td>1/2</td>
<td>110pc</td>
</tr>
<tr>
<td>Region III</td>
<td>20%</td>
<td>&lt;10%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fahrion+ 2016
Dimaratos+ 2015

Porosity and CO-dark gas linked to evolution
Conclusions

✧ Modeling HII region + PDR in individual low-metallicity galaxies: representative physical conditions ($G_0$, $n_H$, $A_V$)

✧ **HII region**: hard radiation fields, low densities, large filling factor

✧ **PDR**: moderate $G_0$, high densities, small filling factor

✧ **Mass budget**: most of the molecular gas is *not* traced by CO
   No clear dependence of CO-dark gas with metallicity but rather on $G_0$ / evolution of regions ($A_V$)

☐ Need more constraints on the cold phases (CI, CO) with ALMA

☐ Need more large-scale mapping in local galaxies (IC10, Magellanic Clouds, NGC6822…)

☐ Take into account dynamics and more realistic geometries