Tracing the chemistry in the clumpy shells around IRC+10216 with the VLA

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Karl Menten, Tomasz Kamiński, Mark Claussen, Leen Decin, Alex de Koter, et al.
AGB stars and their circumstellar envelopes

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2. Methods

The CSE model described in McElroy et al. (2013) was employed and extended in the present work. Specific details can be found in Sect. 3, followed by the concluding remarks and details for the evaluation of photodissociation rates for improvements in N_2 self-shielding. The importance of self-shielding of molecules in the interstellar medium (ISM). This study focusses on the outer CSE where chemistry is mainly driven by the photodissociation of CO using the self-shielding functions for N_2 (Spelsberg & Meyer 2001; Lewis et al. 2005; Lewis et al. 2008b; Lewis et al. 2008a; Heays et al. 2011) and theoretical (e.g., Helm et al. 1993; Sprengers et al. 2004; Stark et al. 1989; Turner 1983). Even with an approximate treatment of CO self-shielding, the importance of self-shielding of molecules in the CSE was first noticed for CO some 30 years ago (Morris & Jura 1974; Herbst et al. 1977) or its deuterated form, N_2D_2. However, absolute unshielded rates have been identified in IRC 10216. A full description of the SS model used for calculating photorates is reduced at the level of dust shielding. It is important to realize that the uncertainty in the photorates is reduced by an order of magnitude. Also, we employ a new fully spherically-symmetric (SS) model over the past decades. While the paper is organised as follows: the CSE model, the improvements in N_2 self-shielding, and employ a new fully spherically-symmetric (SS) model with respect to the previous values (van Dishoeck 1988).
The carbon star IRC+10216

- Often-studied carbon-rich AGB-star a.k.a. CW Leo
- Cool and luminous: \( \sim 2700 \) K, \( \sim 10,000 \) \( L_\odot \)
- Pulsation period: \( \sim 630 \) days
- Nearby: \( \sim 130 \) pc
- High mass-loss rate: \( 2 \times 10^{-5} \) \( M_\odot \) yr\(^{-1} \)
- Mass estimate: \( \sim 1 - 2 \) \( M_\odot \)
- C/O \( \sim 1.4 \)
- more than 80 molecules detected

Distribution of molecules and dust

Leão et al. 2006 (VLT)  

2 arcmin

Trung&Lim 2008 (VLA)

CO(J=2-1)  
Cernicharo et al. 2014 (IRAM 30m)

100  -100

CO(2-1) + dust (PACS 100µm)  
Cernicharo et al. 2014 & Decin et al. 2011

~ 15 600 AU  
~ 2 \times 10^{15} \text{ m}
The VLA survey of IRC+10216

- Karl G. Jansky Very Large Array, New Mexico, USA
  Interferometer: 27 antennas (25m) with new receivers, new correlator

- Spectral line and imaging survey of IRC+10216 in 2011 and 2013
  (Mark Claussen, NRAO)

- Large coverage & bandwidth: 18 - 50 GHz, 2 GHz

- Unbiased unprecedented detail of ~1 arcsec resolution and
  ~1 mJy (per 125 kHz) sensitivity in ~ 51 hrs in total

- Tracing UV-induced photochemistry of outer CSE
The VLA survey of IRC+10216

Keller et al., in prep.

within 45”
The VLA survey of IRC+10216

Almost 20 species identified so far:

HC$_3$N  HC$_5$N  HC$_7$N  HC$_9$N
C$_3$N  C$_3$H  C$_4$H  C$_5$H  C$_6$H  C$_8$H
C$_3$N$^-$  C$_5$N$^-$  C$_6$H$^-$
MgNC  NaCN  C$_2$S  C$_3$S  C$_4$Si  SiS
+ isotopologues
+ vibrationally excited states
The VLA survey of IRC+10216

Keller et al., in prep.
The VLA survey of IRC+10216

Keller et al., in prep.
HC$_3$N, HC$_5$N and HC$_7$N

Keller et al., in prep.
Morphology of CSE

• Mass loss process is variable
  ➔ stellar pulsations?
  ➔ cyclic magnetic activity?
  ➔ binary system?

• Companion-induced spiral structure?
  ➔ Orbital period: 55 yr, 800 yr
    (Decin et al. 2014, Cernicharo et al. 2014)
  ➔ Position angle ~ 20 deg (Decin et al. 2014)

• Photochemistry of cyanopolyynes and hydrocarbons
Photochemistry around IRC+10216

Chemical model without density-enhanced shells

Chemical model with density-enhanced shells

expected radius: 15"
expected width: 2"

Cordiner&Millar 2009
Morphological analysis

- Radial intensity profiles (assuming constant symmetric velocity field)
- Stellar position offset from center of emission
- Compare different quarters in detail

Denise Keller
14 December 2015

Keller et al., in prep.

**Preliminary**

HC$_3$N(3-2)
Radial profiles

Keller et al., in prep.
Radial profiles

<table>
<thead>
<tr>
<th>Q2</th>
<th>Q1</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>average radius Q2:</td>
<td>average radius Q1:</td>
<td>average radius Q3:</td>
<td>average radius Q4:</td>
</tr>
<tr>
<td>HC$_3$N: 17.9 ± 1.4”</td>
<td>HC$_3$N: 14.0 ± 2.0”</td>
<td>HC$_3$N: 16.4 ± 1.5”</td>
<td>HC$_3$N: 12.9 ± 1.3”</td>
</tr>
<tr>
<td>HC$_5$N: 20.0 ± 1.8”</td>
<td>HC$_5$N: 15.4 ± 1.9”</td>
<td>HC$_5$N: 18.3 ± 0.8”</td>
<td>HC$_5$N: 14.2 ± 0.8”</td>
</tr>
<tr>
<td>HC$_7$N: 21.9 ± 8.0”</td>
<td>HC$_7$N: 16.5 ± 7.7”</td>
<td>HC$_7$N: 19.0 ± 4.2”</td>
<td>HC$_7$N: 15.4 ± 5.0”</td>
</tr>
<tr>
<td>C$_3$N: 21.3 ± 6.5”</td>
<td>C$_3$N: 17.2 ± 25.6”</td>
<td>C$_3$N: 19.8 ± 11.2”</td>
<td>C$_3$N: 16.0 ± 14.1”</td>
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<tr>
<td>average widths: 3-4”</td>
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</tbody>
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- Average radius increases:
  HC$_3$N $\Rightarrow$ HC$_5$N $\Rightarrow$ HC$_7$N $\Rightarrow$ C$_3$N
  Q4 $\Rightarrow$ Q1 $\Rightarrow$ Q3 $\Rightarrow$ Q2
- Chemistry and dynamics
- Refinement of fitting routine
- Further careful statistical analysis necessary
Summary

- New spectral line and imaging VLA survey of IRC+10216

- Detailed morphology analysis of carbon-bearing molecules

- Improve knowledge of morphology, mass loss history and chemistry of carbon-rich AGB stars