The Impact of Interferometry on the Detection of Large Molecules

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ALMA basics:

Angles: resolution of ALMA

\[ \theta (\prime\prime) = 0.2 \ \lambda (\text{mm}) / \text{baseline (km)} \]

(at \( \lambda = 3 \ \text{mm} \), baseline 150m, \( \theta = 3.5 \prime\prime \))

For 50 antennas + ACA, \( \lambda = 3 \ \text{mm} \), \( \Delta V = 3 \ \text{km s}^{-1} \), 1h on get \( \Delta T_{\text{RMS}} = 4.0 \ \text{mK} \), \( S_{\nu} = 0.5 \ \text{mJy} \)

(Sensitivity calculator for 12m dishes):
http://www.eso.org/projects/alma/science/bin/sensitivity.html
Opacity of the Atmosphere

In mm, sub-mm, need an excellent site
VLA Compact Configuration

Inner part of the compact configuration of the Very Large Array.
(Note the large separation between dishes).
BIMA: ten 6m antennas, $A_g=283m^2$
OVRO: Six 10.4 m antennas, $A_g = 510 \text{m}^2$
Plateau de Bure: Now with six 15m antennas: $A_g=1060 \text{ m}^2$

(One antenna added after photo taken)
CARMA: six 10.4m, nine 6m, eight 3.5m dishes
$A_g = 842 m^2$
ALMA + ACA: Early Sci 09/10; $A_g$ up to $7238\text{m}^2$

(64) + 913$m^2$ (four 12m single dish + twelve 7m)

The four 12m dishes in the lower right are for total power measurements
## Comparison for 3 mm

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Point Source sensitivity*</th>
<th>largest structure#</th>
<th>FOV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARMA</td>
<td>3.7 mJy</td>
<td>80”</td>
<td>177”</td>
</tr>
<tr>
<td>PdeB</td>
<td>3.2</td>
<td>19”</td>
<td>41”</td>
</tr>
<tr>
<td>ALMA(50+ACA)</td>
<td>0.5</td>
<td>all</td>
<td>88”</td>
</tr>
</tbody>
</table>

*One hour on source, with a 3 km s\(^{-1}\) wide resolution, & equal receiver noise temperature, weather conditions

#In the past, in some cases, single dish and interferometer data have been combined, but these were on a case by case basis. For ALMA this possibility will be the norm. Also calibrations will be more secure, better S/N ratios
Astronomical Facts for Discoveries of Interstellar Molecules

- Need *at least* 10 lines clearly detected with a good S/N ratio (for some high profile cases, even more!)
  - There are exceptions such as $\text{H}_2\text{D}^+$
- These lines must fit a single population
  - Implies quasi equilibrium distribution
- **Under No Circumstances** can there be instances where allowed transitions are not found
- With interferometers, the lines *must* have the same positions
Mundane Facts

Populations of linear molecules increase as \( \sim (2J+1) \) & symmetric tops
As \( \sim (2J+1)^2 \), until a given \( J \), then sharply fall as \( \sim e^{-\Delta E_u/kT} \)
Thus should not seek highly excited lines in cold or low density sources.

**Asymmetric Top**

*Total population* \( \sim T^{1.5} \)

The asymmetric top molecules have
Many more transitions! The populations are
Spread over many more energy levels. If one measures only a line, one may not be able to detect rare species.
History

• Up to now the only molecule found with an interferometer is acetic acid (with BIMA confirmed with OVRO)

• Some sources preferred for certain types of molecules
  – large complex species in SgrB2(N)-LMH)
  – long carbon chains in TMC-1, a cold source ($T_k=10K$) in Taurus

• Even within a given source, some components have larger abundances of complex molecules (SgrB2(N)-LMH)
Test Case for ALMA: SgrB2(N)

1.3 cm continuum toward SgrB2

A model of SgrB2 from 1.3 cm NH$_3$ data; the envelope temperature is now thought to be about 700 K from ISO lines of ammonia

From the KP 12m Dish.

The cross-hatched regions have H$_2$ densities of order 10$^7$ cm$^{-3}$
Additional Data

• Hollis et al. (2004) find 4 transitions toward SgrB2(N) which give a value of $T_R = 8K$
  – This is in contrast to the mm lines that gave $T_R$ of $\sim 50$ K
  – Hollis et al. speculate that there are two regions, one warm and the other cold.

Surprising since NH$_3$ data shows that all gas in Galactic Center is hot
A surprising result is that complex species may arise from an extended region in SgrB2.

Evidence from Chengalur & Kanekar (2003) measurements of acetaldehyde (CH$_3$CHO) at 30 cm.

Integrated line intensity traces the continuum: This transition is probably a weak maser, but this species must be extended over arc minutes.
What Can ALMA Do?

- In Sgr B2, want to be able to detect species known to be there already.
  - Glycolaldehyde, Acetic Acid, Acetone, Ethylene Glycol, methyl formate, etc.
  - Obtain accurate positions and sizes to model chemistry
  - Search for new species
    - Sensitivity better than any other mm/sub-mm facility
    - Has the total power i.e. ‘zero spacing’ information
    - At least as good as large dishes for spread out emission, better than any instrument for very compact emission.
Structure Studies

- **Example:** SgrB2
  - ALMA will produce new information about structure and dynamics of both the cores and the envelope
  - Determine where the molecules such as CH$_3$CHO are produced
  - Determine heating source for extended gas

LOW DENSITY ENVELOPE
$T_e > 200K$
$n$(H$_2$) $\leq 5 \times 10^3 cm^{-3}$
D $\sim 20pc$

MODERATE DENSITY REGION
$n$(H$_2$) $\sim 10^5 cm^{-3}$
ALMA Data for SgrB2

- **In each 8 GHz wide band, have 16 spectrometers for each polarization.**
  - Each of the spectrometers can be tuned individually in the band
  - Can measure 16 spectral regions simultaneously
- With single dish flux density measurements have all spatial scales to the angular resolution given by the largest interferometer baseline spacing
  - In this case 4"
- At 3 mm, can detect lines of acetone found with the KP 12m dish in 1h (on source) with a 10:1 S/N ratio if the emission is spread over the whole KP 12m beam. If the emission is compact, the result is better.
  - with a 3 km s⁻¹ velocity resolution reaches the sensitivity of previous searches
  - Each of the spectrometer covers 1,500 km s⁻¹
  - This covers a 50” region. To image all of SgrB2 continuum sources require a mosaic of 9 positions.
  - Could also image the dust continuum
  - Total time of 15 hours with calibrations
- Total number of data points is 10⁸ (5,625 spatial x 16.384 frequency)
ALMA and Orion KL

• Even easier since the Hot Core and Compact Ridge are more concentrated.
• Would need to use narrower velocity resolution, so noise is a factor of 2 larger
• In continuum would also detect the O-B stars and dust continuum in the region.
• To include Orion-S (90” south of KL), would require a 3 position mosaic
  – Total time of 15 hours
Orion KL: The Classical Hot Core Source

Within a 20" region there are a variety of physical conditions.

Lots of NH₃

Lots of Quasi-thermal methanol

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Orion KL Geography

- Hot Core has lots of nitrogen bearing molecules
- The compact ridge seems to favor molecules with more oxygen
- Outflows are energetic, from source I
- Embedded sources in the Hot Core provide local heating
- This is not really a source for the most complex molecules
  - SgrB2(N)-LMH is the best source (and passes overhead in Chile!)
Other Prime Sources

• NGC6334
  – 1.5 kpc from Sun, with source components separated spatially
  – Narrower lines
  – Rich spectrum
  – Less studied but good source for ALMA
  – I(N) interesting—seems to be very young
Example of an ALMA Observe Tool Set Up
How can this amount of data be analyzed and interpreted?

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Complex Molecules in Space: Present and Future Prospects with ALMA
Additional Needs

- Laboratory measurements and complete data bases to aid identifications