Molecular gas in the immediate vicinity of Sgr A* seen with ALMA

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Next month: ALMA Regional Center (ARC) node · University of Bonn

IAU Symposium 322 · July 20th, 2016

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Outline

Continuum emission
- Spectral index

Molecular gas
- CA
- SEW
- Triop
- V-cloud / SEE

minispiral
100 GHz continuum emission (ALMA, 1.5“ beam)

stars - dust
1.27, 1.39, and 1.57 μm
(HST; background image)
The Galactic Center (GC) continuum information

Older data ...

CARMA 230GHz, beam: 0.9'', Kunneriath et al. 2011
GC – continuum seen by ALMA

100 GHz – 1.5"
80’’x 80’’

250 GHz – 0.75"
40’’x 40’’

340 GHz – 0.5"
20’’x 20’’

ALMA C0 data set (PI: H. Falcke):
- Monitor Sgr A*
- Cycle through all 3 bands
- One configuration

Highest resolution at this frequency so far
First resolved 340 GHz map ever
Highest resolution in sub-mm
GC — continuum spectral index

$\alpha_{100-250} = 0.58 \pm 0.21$
$\alpha_{250-340} = 0.17 \pm 0.45$

Kunneriath et al. (2012a,b), Falcke et al. (1998b), Marrone et al. (2006b), Eckart et al. (2012), Bower et al. (2015)
GC — spectral information of ALMA data

100 GHz (1.5'' - 50 km/s):
• $^{13}$CS, N$_2$H$^+$, CH$_3$OH
• H39$\alpha$, H51$\beta$, H49$\beta$

250 GHz (0.75'' - 20 km/s):
• CS, HC$_3$N, H$^{13}$CO$^+$, SiO, SO, C$_2$H
• H36$\beta$

340 GHz (0.5'' - 15 km/s):
• CH$_3$OH, SiO
• H33$\beta$

high density (hd), hd – warm, hd – cold, shocks, recombination, photodissociation region (PDR)
40'' x 40''

ionized gas
250 GHz continuum emission (ALMA, 0.75'' beam)

molecular gas
CS(5-4) emission (ALMA, 0.75'' beam)

stars & warm dust
3.8 μm (VLT – NACO, Sabha, priv. comm.)

Moser 2016
GC - central association (CA)


<table>
<thead>
<tr>
<th>Ratio</th>
<th>CA</th>
<th>SEW</th>
<th>Triop</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS / C₂H</td>
<td>5 - 7</td>
<td>5 - 7</td>
<td>1 - 2</td>
</tr>
<tr>
<td>CS / SO</td>
<td>5 - 15</td>
<td>5 - 8</td>
<td>2 - 4</td>
</tr>
<tr>
<td>CS / H¹³CO⁺</td>
<td>5 - 16</td>
<td>8 - 14</td>
<td>2 - 4</td>
</tr>
<tr>
<td>CS / SiO</td>
<td>5 - 17</td>
<td>7 - 9</td>
<td>3 - 5</td>
</tr>
<tr>
<td>CS / C³S</td>
<td>-</td>
<td>28 - 33</td>
<td>5 - 7</td>
</tr>
<tr>
<td>C₂H / SO</td>
<td>1.3 - 2.1</td>
<td>1.0 - 1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>C₂H / H¹³CO⁺</td>
<td>1.8 - 3.0</td>
<td>2.1 - 2.6</td>
<td>1.5</td>
</tr>
<tr>
<td>C₂H / SiO</td>
<td>2.2 - 2.6</td>
<td>1.1 - 1.9</td>
<td>-</td>
</tr>
<tr>
<td>SO / SiO</td>
<td>1.0 - 2.4</td>
<td>1.2 - 1.7</td>
<td>1.1</td>
</tr>
<tr>
<td>SO / H¹³CO⁺</td>
<td>0.7 - 1.9</td>
<td>1.7 - 2.3</td>
<td>1.2</td>
</tr>
<tr>
<td>SiO / H¹³CO⁺</td>
<td>0.6 - 1.7</td>
<td>1.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>
GC - central association (CA)

- 3x higher CS/X line ratios than CND
  (X: other ALMA molecules)

- **higher excitation**
  (temperature – Goto 2014)
  IR-pumping

- + **enhanced abundance**
  UV- and/or X-ray emission

- **CA closer** than CND

- **CA: infalling clump?**
  denser cloud cores embedded in diffuse gas
OH-streamer head at 1667 MHz on 18 cm continuum  Karlsson 2015  
(greyscale: Sgr A West/ minispiral, +: Sgr A*)

OH-streamer (15 - 45 km/s, Karlsson et al. (2015), 100 GHz continuum,  
CS(5-4) , Sgr A*, 40’’ x 40’’

GC – origin of CA
OH-streamer head at 1667 MHz on 18 cm continuum  Karlsson 2015 (greyscale: Sgr A West/ minispiral, +: Sgr A*)

- **Head:** 65 $M_\odot$ (Karlsson 2015)
- **CA:** 7 $M_\odot$ (n~$10^5$ cm$^{-3}$)
ionized gas
250 GHz continuum emission (ALMA, 0.75″ beam)

molecular gas
CS(5-4) emission (ALMA, 0.75″ beam)

stars & warm dust
3.8 μm (VLT –NACO, Sabha, priv. comm.)
GC - Triop

- prominent molecular line emission (CARMA, SMA, ALMA, literature)
- complex molecules
- shielded from UV
- $\text{HC}_3\text{N}$ with $E_u \sim 150\text{K}$
- $\text{CH}_3\text{OH}$ class I maser (15’’ beam, Yusef-Zadeh 2007)

→ hot core/early star formation (SF)?
GC

IR dark clouds (IRDC) & class I methanol masers (36 & 44 GHz) (Yusef-Zadeh et al. 2001; Sjouwerman et al. 2010; Pihlström et al. 2011)

HST NICMOS 1.9µm
GC – summary & outlook

- Highest spatial resolution at 250 and 340 GHz
- Clumps-catalogues: position, size, flux, ratio, velocity, line width

- **Continuum emission** - Spectral index
  - Dust vs. ionized gas

- **Molecular gas** - Line ratios - trends
  - CA – high excitation!
  - infalling clump? – Kin/Dyn
  - SEW – excitation similar to CA
  - Triop – complex molecules
  - V-cloud / SEE – IR dark clouds

- External radiation
  - hot core chemistry
  - cold core chemistry
Approaching hell’s kitchen: molecular daredevil clouds in the vicinity of Sgr A*

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Received 26 February 2016

Abstract

NGC 6502, a radio source and the northernmost feature of the nuclear ring in the Sagittarius B Molecular Complex, is observed with the Atacama Large Millimeter/submillimeter Array (ALMA) in band 3, 6, 7 and 12, providing an up to now highest resolution (<0.5") view of the Galactic Center. We present the results of the 100 GHz continuum and the H3α emission we obtain a uniform electron density in the complete minispiral. The spectral index of Sgr A* is ~ 0.5 at 100 - 250 GHz and ~ 0.0 at 230 - 340 GHz. The spectral indices in the center show spectral indices (S ∝ ν^α) around -0.1 implying Bremsstrahlung emission, while dust emission is the dominant mechanism in the minispiral exterior. Apart from CS, which is most widespread in the center, also H¹³CO⁺, HC₅N, SiO, SO, C₂H, CH₃OH, H₂CS and N₂H⁺ are detected. The bulk of the clumpy emission regions is at positive velocities and in a region confined by the minispiral Northern Arm, Bar and the sources IRS 3 and 7. Though partly spatially overlapping with the radio recombination line (RRL) emission at same negative velocities, the relation to the minispiral remains unclear. A likely explanation is an infalling clump consisting of denser cloud cores embedded in diffuse gas. The central association of clouds shows three times higher CS/X (X: any other observed molecule) ratios than the circumnuclear disk (CND) suggesting a combination of higher excitation - by a temperature gradient and/or IR-pumping - and abundance enhancement due to UV- and/or X-ray emission. Hence, we conclude that this central association is a secondary source of ionization.