Complex organic molecules in the interstellar medium in the era of ALMA

Arnaud Belloche

MPIfR, Bonn

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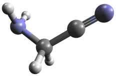
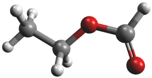
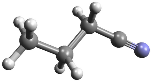
Max-Planck-Institut für Radioastronomie

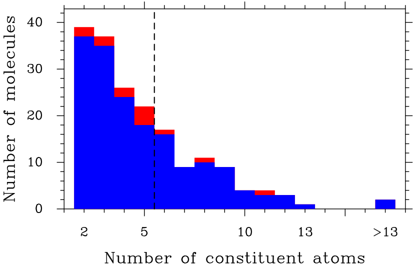






Complex organic molecules in the ISM

Molecules in the interstellar medium



(http://www.cdms.de/)

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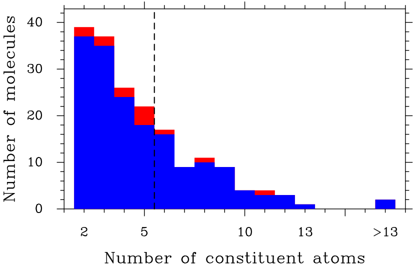

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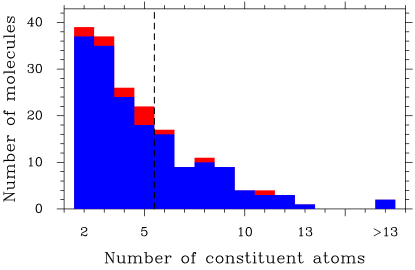

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- complex molecules (for astronomers): **≥ 6 atoms** (Herbst & van Dishoeck 2009)
- one third of detected molecules are **complex**
- all detected complex molecules are **organic** (COMs)

Where are complex organic molecules found in the ISM?

A number of environments with different chemistries

- **hot cores** (> 100 K): e.g., Sgr B2, Orion KL, W51 e1/e2, NGC 6334(I)
  (e.g., Snyder et al. 1994, Ziurys et al. 1993, Ikeda et al. 2001, Bisschop et al. 2007)
- **hot corinos** (> 100 K): e.g., IRAS 16293, NGC 1333-IRAS 4A
  (e.g., Cazaux et al. 2003, Bottinelli et al. 2004)
- **lukewarm corinos** (< 100 K): e.g., L1527
  (e.g., Sakai et al. 2008)
- **cold, quiescent regions** (~ 10 K): e.g., TMC 1, L1689B, B1-b
  (e.g., Suzuki et al. 1986, Bacmann et al. 2012, Cernicharo et al. 2012)
- **shocked regions**: e.g., CMZ clouds, L1157 outflow
  (e.g., Requena-Torres et al. 2006, Arce et al. 2008)
- **circumstellar envelopes around evolved stars**: e.g., IRC+10216
  (e.g., Cernicharo et al. 2000)

(see also Herbst & van Dishoeck 2009)

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Chemical processes

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⇒ **predictions of these models need to be tested!**

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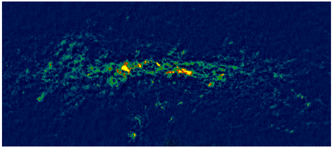
- did the ISM contribute to **seeding life** on Earth?
- are such molecules **widespread** in the Galaxy?
- what is the degree of **chemical complexity** in the ISM?

The massive star-forming region Sgr B2



Galactic Center at 870 μm
(ATLASGAL/LABOCA/APEX, Schuller et al. 2009)

The Sgr B2 molecular cloud

- most massive star forming region in our Galaxy (5–10 10^6 $M_\odot$)
- about 100 pc from Galactic Center
- contains 2 massive clumps (N and M), hosting clusters of UC H II regions
- best hunting ground for COMs?
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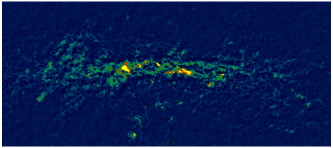

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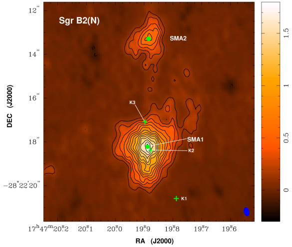

(SMA 850 μm, Qin et al. 2011)

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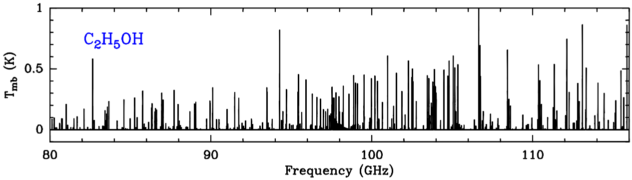
Sgr B2(N)

- very high column density ($> 10^{25}$ cm^{-2} over few arcsec)
- two hot cores with different $V_{\rm lsr}$ (diff.: 10 km s^{-1}; sep.: 5″, i.e. 0.2 pc)

The need for unbiased line surveys

- complex molecules emit hundreds of (weak) rotational lines



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  ⇒ many lines are blended (confusion limit!)

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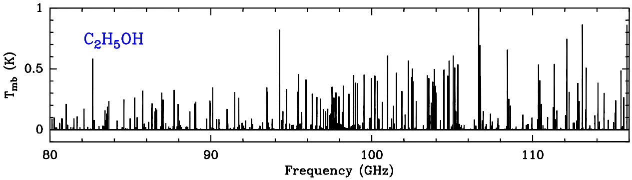

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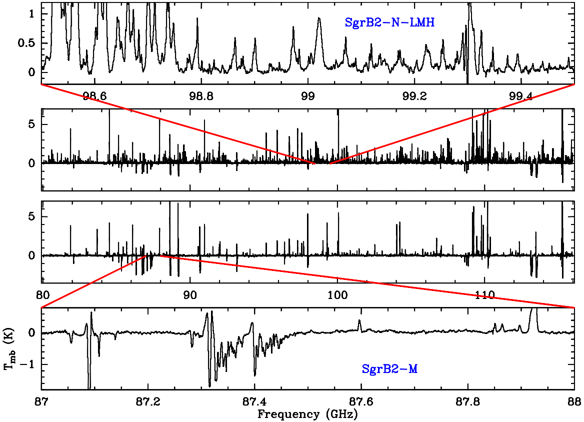
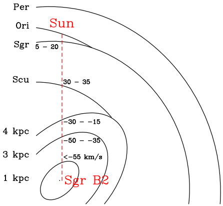
  ⇒ many lines are blended (confusion limit!)
- secure identification of a complex molecule requires:
  (see also Snyder et al. 2005, Halfen et al. 2006)
  - identification of a large number of lines of this molecule
  - no missing line
  - consistent relative line intensities
  - modeling emission of all known molecules
    (to point out blended lines and prevent mis-assignments)

Single-dish line survey of Sgr B2

Single-dish line survey of Sgr B2 at 3 mm



IRAM 30 m telescope



- Sgr B2(N): 3700 lines above 4σ, 100 lines per GHz
- Sgr B2(M): 950 lines above 4σ, 25 lines per GHz

Main results of the single-dish 3 mm survey

(Belloche et al., 2013, A&A, 559, A47)

Overview

- LTE modelling with XCLASS, using CDMS/JPL spectroscopic databases
  (XCLASS also available in CASA. Other softwares: e.g., Weeds in CLASS, CASSIS)
- 70% of detected lines identified in Sgr B2(N) (47% in Sgr B2(M))
- 56 molecules, 66 isotopologues, 59 vib./tors. excited states in Sgr B2(N)
  (46/54/24 in Sgr B2(M))

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Detection of "new" complex organic molecules

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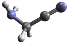

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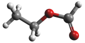

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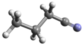

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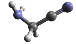

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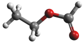

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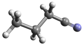
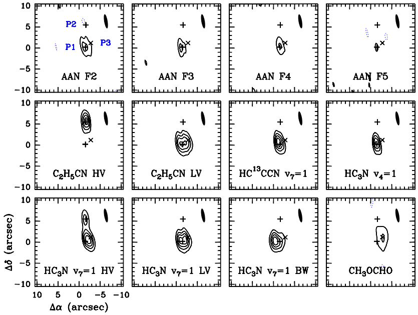


Other first detections in space

- ^{13}C isotopol. of vinyl cyanide (C_2H_3CN, Müller et al. 2008), $H^{13}CC^{13}CN$, $H^{13}C^{15}N$
- 12 new vib. or tors. excited states of known molecules

Line survey of Sgr B2 with ALMA

The need for high angular resolution



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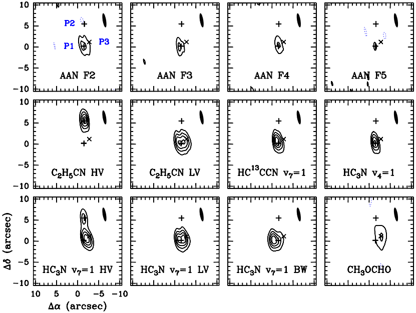

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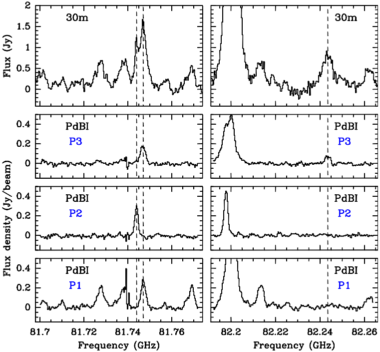


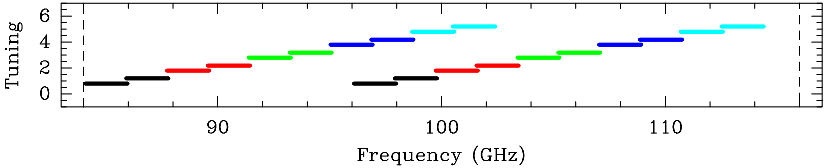
- all transitions of a molecule should trace the same region(s)
- resolution < 5′′ needed to separate the two hot cores in Sgr B2(N)
  < 2′′ needed to resolve the velocity structure of main hot core

⇒ bring down the confusion limit!

ALMA project performed/scheduled in Cycle 0/1

Unbiased 3 mm line survey of Sgr B2(N) in Cycle 0/1 (PI: A. Belloche)

- bandwidth: 84 to 111/114.4 GHz with 4/5 tunings only
- angular resolution: 1.8″/1.4″
- sensitivity: 16×/26× better than the IRAM 30 m survey



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Status

- Cycle 0: data reduction in progress
- Cycle I: setup not observed yet

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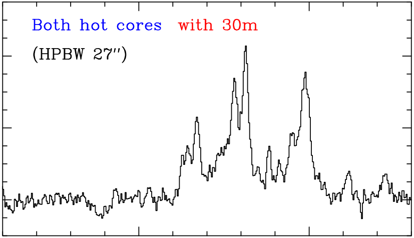

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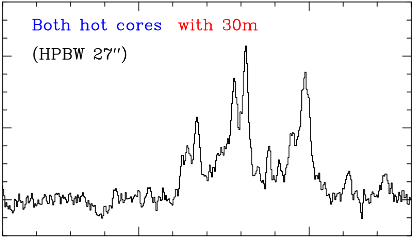

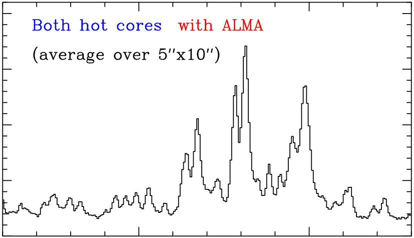

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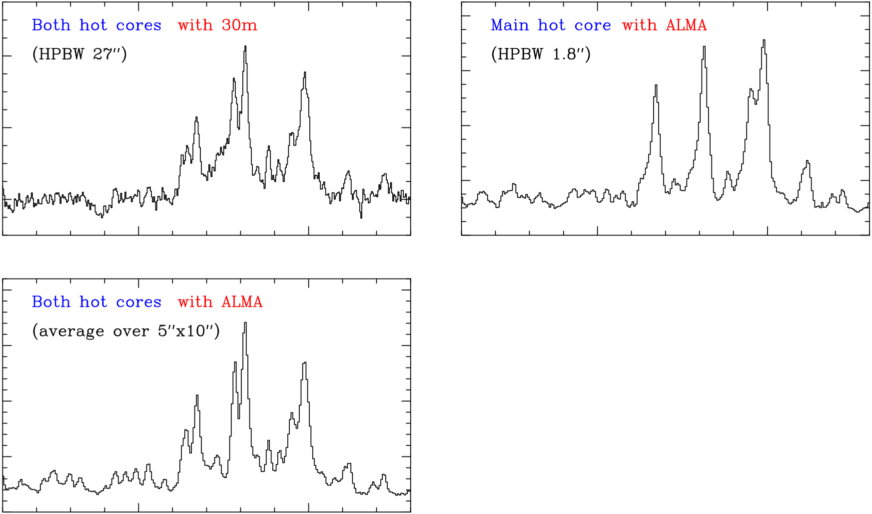

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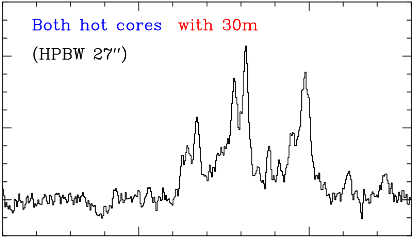

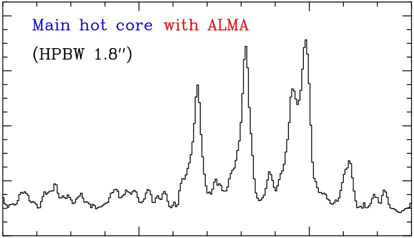

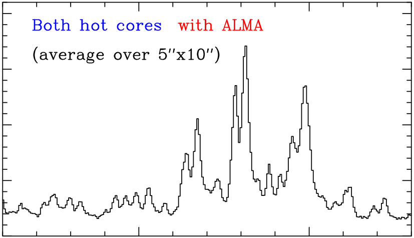

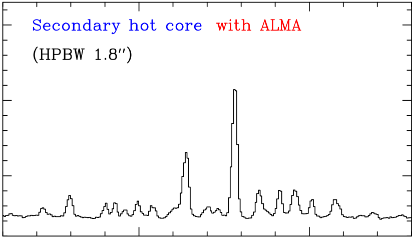

Perspectives

The bright future of interstellar COMs

1100 lines still unidentified in single-dish 3 mm line survey of Sgr B2(N)

- crucial need for (lab.) spectroscopic data of vibrationally and torsionally excited states and isotopologues of known molecules to remove the “weeds”
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