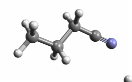
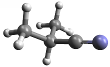
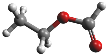
Complex organic molecules in hot cores

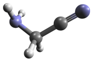
Arnaud Belloche

MPIfR, Bonn (Germany)









High-Resolution Submillimeter Spectroscopy of the
Interstellar Medium and Star Forming Regions –
From Herschel to ALMA and Beyond

Zakopane, 14 May 2015

Collaborators:
R. Garrod (Univ. of Virginia), H. Müller (Univ. of Cologne), K. Menten (MPIfR)

Max-Planck-Institut
für Radioastronomie

MAX-PLANCK-GESELLSCHAFT

Complex organic molecules in the ISM

Search for interstellar COMs: line surveys!

COMs in hot cores

Outlook

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Messengers of interstellar chemistry

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- more than 80 **amino acids** found in **meteorites** on Earth, with isotopic composition and racemic distribution suggesting extraterrestrial origin (e.g., Botta & Bada 2002)

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- what is the degree of **chemical complexity** in the ISM?

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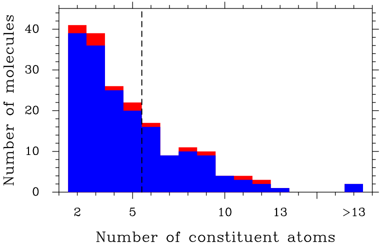

(http://www.cdms.de/)

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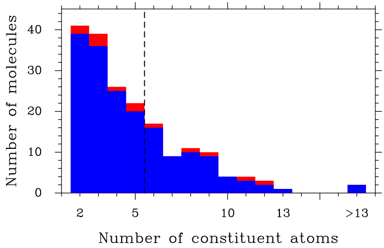

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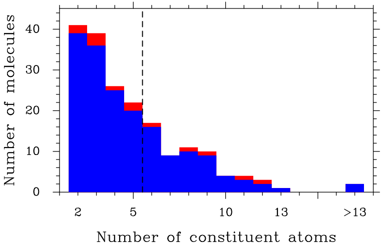

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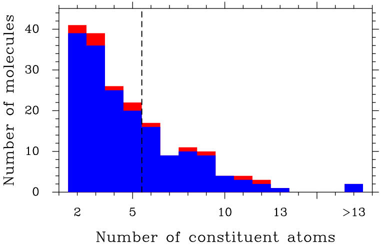

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⇒ **how do COMs form in the interstellar medium?**

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  - reactive desorption of COM precursors followed by radiative association? (Vasyunin & Herbst 2013b)
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⇒ **predictions of chemical models need to be tested observationally!**

Hot cores

(in the perspective of understanding interstellar chemistry of COMs)

- **hot core**: early evolutionary stage during formation of a high-mass star, when protostar starts to heat up its envelope
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- high column densities of hot cores ⇒ key advantage for COM detection
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⇒ **hot cores excellent targets to test chemical models**

Chemistry in hot cores (and corinos)

Three-phase scenario: (Herbst & van Dishoeck 2009)

- zeroth-generation species: COMs formed in gas phase or on grain surfaces during cold prestellar phase

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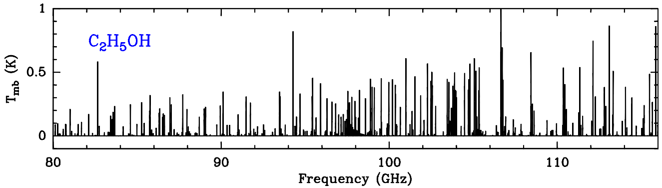
- second-generation species: COMs formed in gas phase after sublimation of grain mantles

Search for interstellar COMs: line surveys!

The need for interferometric line surveys

COMs in hot cores:

- emit hundreds of (weak) rotational lines



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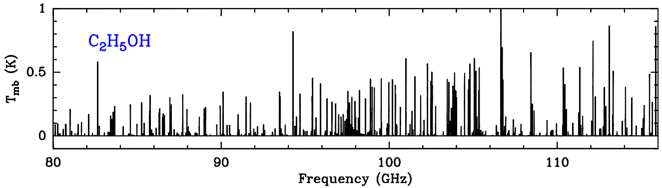

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Secure identification of a COM requires: (see, e.g., Snyder+ 2005, Halfen+ 2006)

- identification of a large number of lines ⇒ **large frequency coverage**
- no missing line ⇒ **unbiased survey**
- consistent relative line intensities ⇒ **radiative transfer modeling**
- no conflict with other molecules ⇒ **model emission of all molecules**
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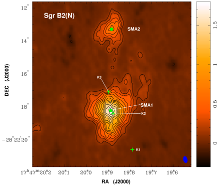
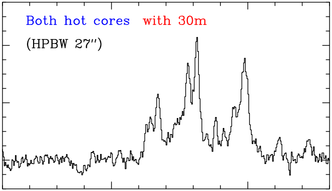
Advent of broadband backends at (sub)mm interferometers (8 GHz@ALMA + soon 16 GHz@NOEMA) ⇒ **efficient line surveys at high angular resolution!**

ALMA: sensitivity and resolution!



Sgr B2(N) at 850 μm

(SMA, Qin+ 2011)



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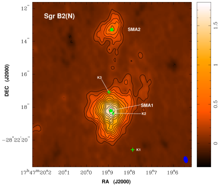

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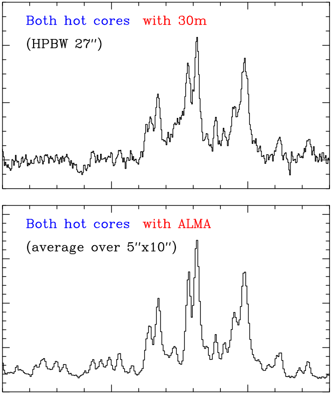

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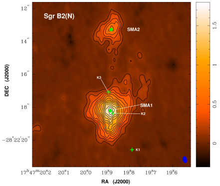

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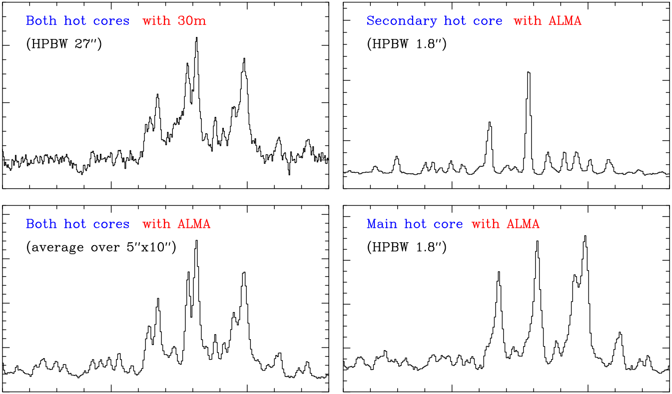

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Modeling of spectral line surveys

Assumptions:

- collision rates missing for many COMs ⇒ LTE often remains unique solution
  (but see, e.g., Faure+ 2014 for non-LTE analysis of methyl formate CH_3OCHO,
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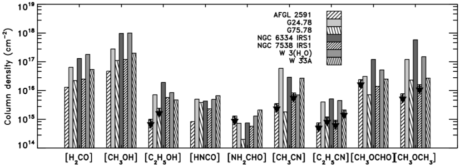
Modeling tools:

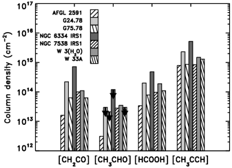
- spectroscopic databases: mainly CDMS and JPL, + other contributions from lab spectroscopists
- predictions for isotopologues and vibrationally excited states of known COMs essential to perform line identification and prevent misassignments
- radiative transfer codes to model emission of each COM: e.g., XCLASS (Schilke+), Weeds (Maret+ 2011), CASSIS (Caux+), MADEX (Cernicharo+)

COMs in hot cores

COMs tracing different “temperature” regimes



“Hot” species



“Cold” species

JCMT/IRAM 30 m survey of COMs toward 7 hot cores: (Bisschop+ 2007)

- COMs classified as either “cold” ($T_{\rm rot} < 100$ K) or “hot” (> 100 K)

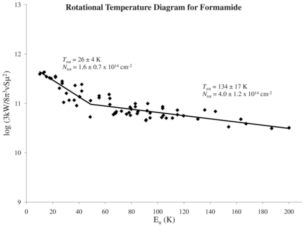
  $\Rightarrow$ two distinct regions (N-containing COMs only in “hot” region)

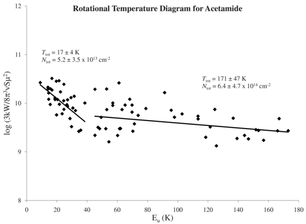
- “hot” species: high abundances, similar $T_{\rm rot}$, correlations between COMs

  $\Rightarrow$ **common solid state formation scheme**

COMs tracing different "temperature" regimes

But some of the "hot" species do also exist in colder regions:





- NH_2CHO and $CH_3C(O)NH_2$ in Sgr B2(N) with ARO 12 m and SMT (Halfen+ 2011):
  - both molecules trace two "temperature" components
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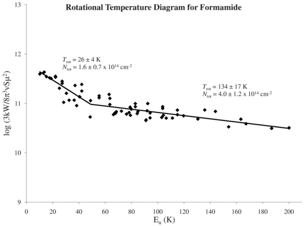

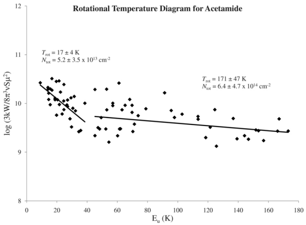

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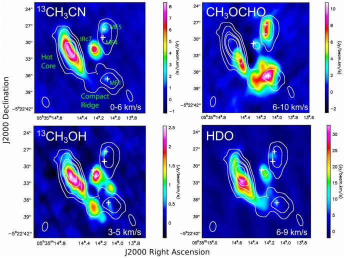
- significant contribution of colder, extended envelope for HNCO and CH_3OH in “line-poor” massive YSOs (Fayolle+ 2015)

Chemical differentiation in Orion-KL

- N- and O-bearing COMs at different locations (Blake+ 1987): different thermal history (Caselli+ 1993)? different grain mantle composition (Charnley+ 1992)?



Orion KL, ALMA-SV (Crockett+ 2014)

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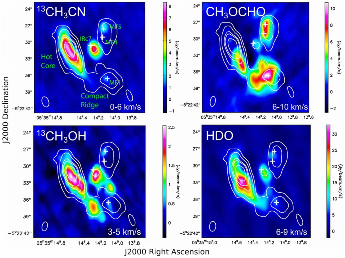

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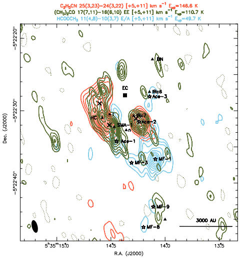
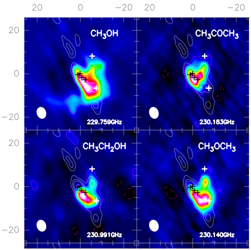


Orion KL, PdBI (Peng+ 2013)



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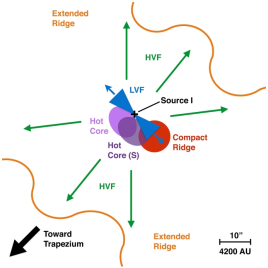

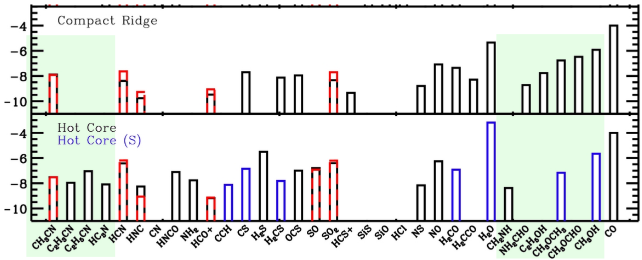

log(N(x)/N(H_2)) in Orion KL (Crockett+ 2014)

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- Analysis of *Herschel*/HIFI line survey based on velocity components (HEXOS, Crockett+ 2014): additional component, hot core (S), with O-bearing species

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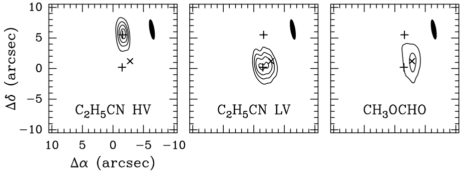

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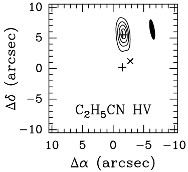

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⇒ **detailed understanding of N/O chemical differentiation will benefit a lot from ALMA**

Constraints on chemistry from series of COMs

Series of alkyl cyanides in Sgr B2(N): (Belloche+ 2009)

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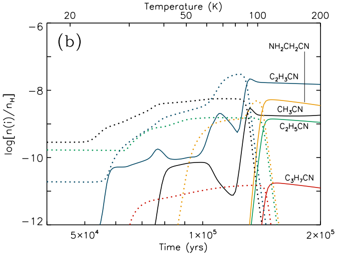

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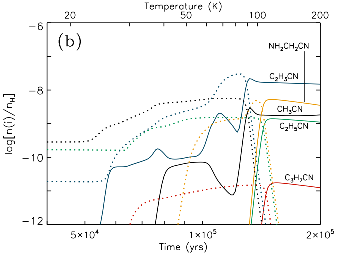

⇒ **expanding COM series sets constraints on their formation process**

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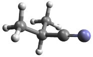

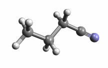

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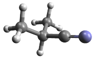

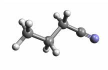

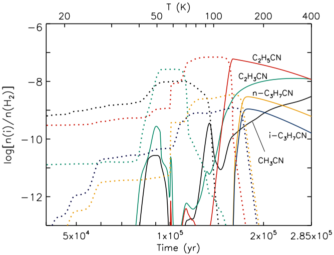

- nearly as abundant as *n*-C_3H_7CN
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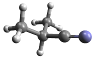

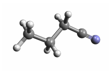

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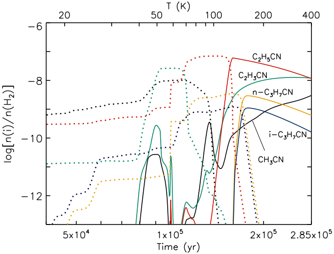

Both molecules formed on grain surfaces but via different formation routes:

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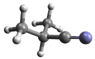

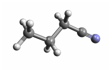

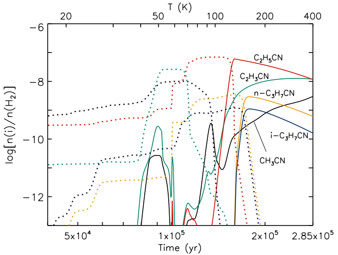

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  (addition of H to propene $CH_2{=}CHCH_3$ strongly favors $CH_3\dot{C}HCH_3$ over $\dot{C}H_2CH_2CH_3$, Curran 2006)

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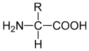
- α-amino acids have a branched heavy-atom backbone: 

  ⇒ detection of *i*-C_3H_7CN **bodes well for presence of amino acids in the ISM!**

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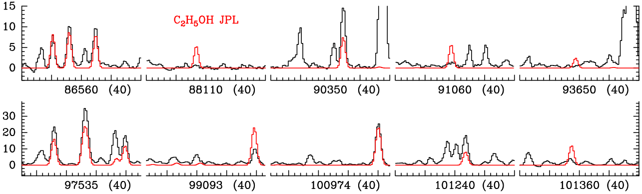
  Example: ethanol C_2H_5OH

ALMA helps improving spectroscopic predictions!

LTE model with official JPL entry of ethanol on top of ALMA Sgr B2(N) spectrum:



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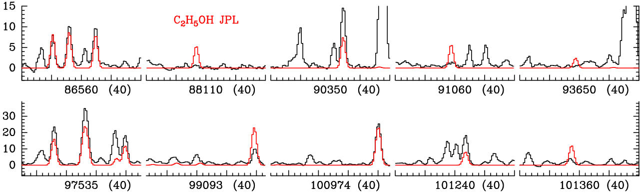

New predictions with gauche a-dipole components turned positive:

(H. Müller, priv. comm.)