Molecular complexity in star forming regions

Arnaud Belloche

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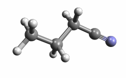
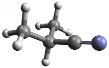


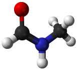


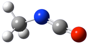
664. Wilhelm und Else Heraeus-Seminar on

Prebiotic Molecules in Space and Origins of Life on Earth

Bad Honnef, Germany

19 March 2018





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SFB 956 Cologne | Bonn

MAX-PLANCK-GESELLSCHAFT

Complex organic molecules in the ISM

Exploring molecular complexity with ALMA

Chemical composition of protostars with NOEMA

Outlook

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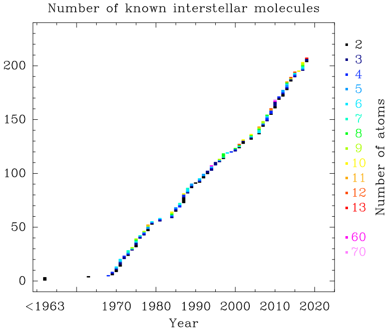
⇒ is molecular complexity of comets/meteorites a **widespread** outcome of interstellar chemistry? What is the degree of **chemical complexity** in the ISM?

Molecules in the interstellar medium



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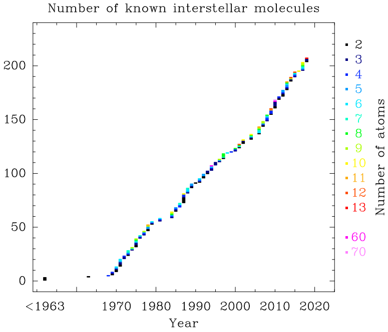

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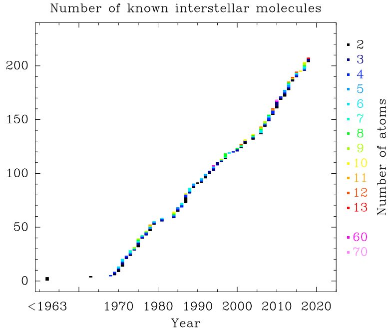

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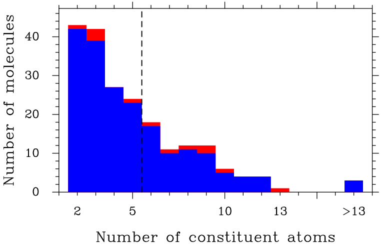

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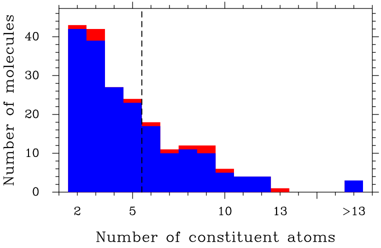

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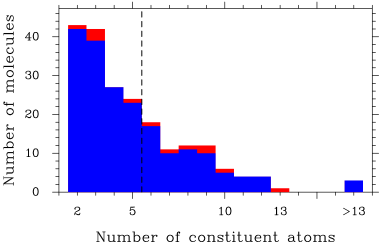

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⇒ **how** do COMs form in the interstellar medium?

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- **COMs** in prestellar cores **at low temperature** (Öberg+ 2010, Bacmann+ 2012):
  - reactive desorption of COM precursors followed by radiative association? (Vasyunin & Herbst 2013b)
  - cosmic-ray induced radical diffusion? (Reboussin+ 2014)
  - non-thermal desorption in core *outer* layers? (Vastel+ 2014, Bizzocchi+ 2014)
  - revision/expansion of gas-phase reaction network? (Balucani+ 2015)

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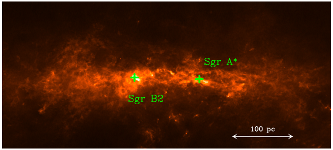
⇒ interplay between **observations**, astrochemical **modeling**, and **experiments**

Exploring molecular complexity with ALMA

The high mass star-forming region Sgr B2



Central Molecular Zone at 870 μm
(ATLASGAL/LABOCA + Planck © MPIfR/A. Weiß)

- one of the most prominent star-forming regions in our Galaxy
  ($\sim 10^7$ $M_\odot$ in $\sim$40 pc diameter, Lis+ 1990)
- about 100 pc from Galactic Center
- contains two dense clumps (N and M) that host clusters of UC H II regions

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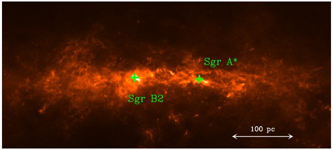

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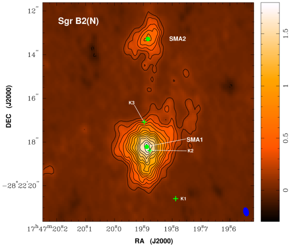

Sgr B2(N) in thermal dust emission
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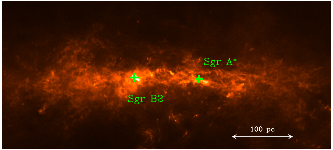

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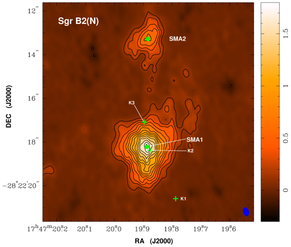

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  $\Rightarrow$ **key advantage for COM detection!**

  (many COMs were first detected toward Sgr B2)

The EMoCA survey: angular resolution matters!

- 3 mm spectral line survey of Sgr B2(N) in Cycles 0 and 1 (84 – 114 GHz) to **search for new COMs** and **test astrochemical models**

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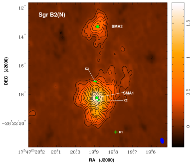

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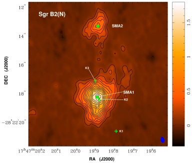

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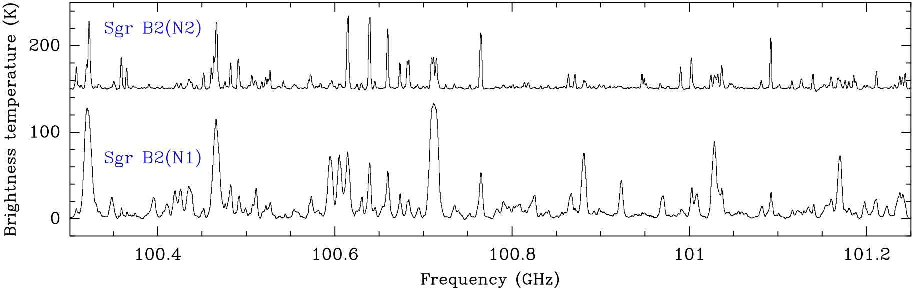

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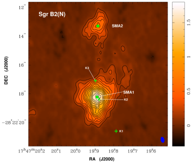

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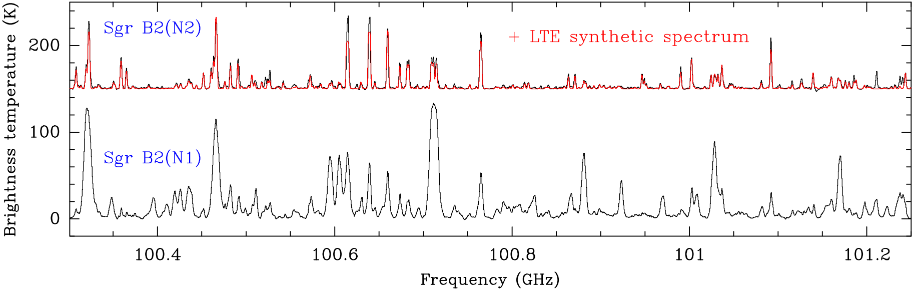
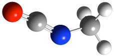


Tentative detection of N-methylformamide

(Belloche et al. 2017, A&A, 601, A49)



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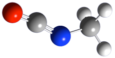

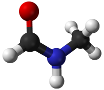

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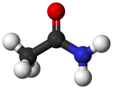

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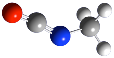

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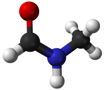

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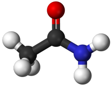

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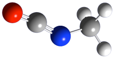

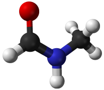

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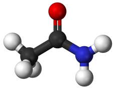

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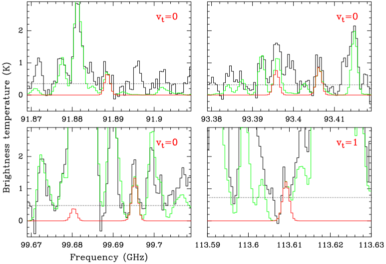

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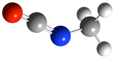

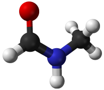

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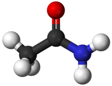

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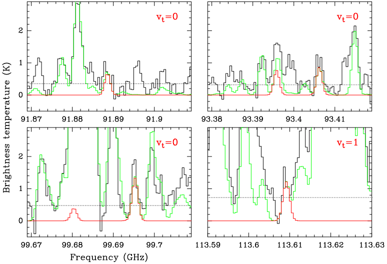

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  $[CH_3NHCHO] / [NH_2CHO] \sim 0.03$
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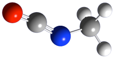

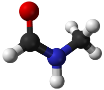

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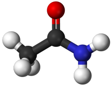

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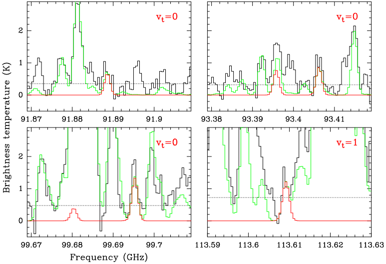

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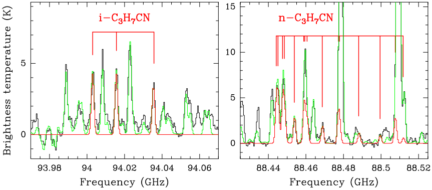
- **chemical modeling** with MAGICKAL (R. Garrod) **supports** tentative **detection** (radical addition reaction CH_3+NHCHO or CH_3NH+HCO, or hydrogenation of CH_3NCO)

Detection of a branched alkyl molecule



(Belloche et al. 2014, Science, 345, 1584)
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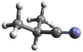

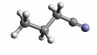

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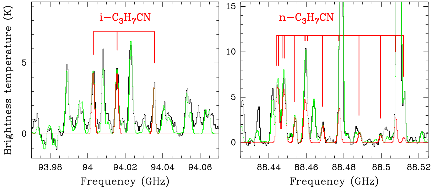

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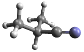

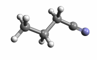

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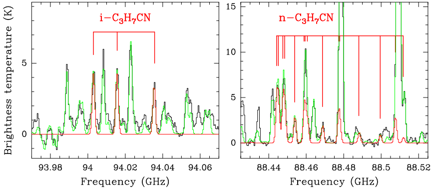

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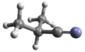

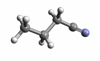

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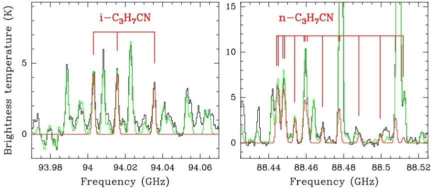

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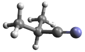

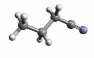

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- amino acids in meteorites: branched isomers even dominate over straight-chain ones (e.g., Cronin & Pizzarello 1983)

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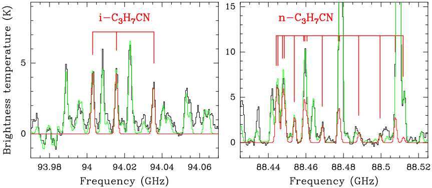

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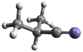

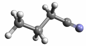

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⇒ **new domain** in structures available to the chemistry of star-forming regions

- amino acids in meteorites: branched isomers even dominate over straight-chain ones (e.g., Cronin & Pizzarello 1983)

⇒ detection of *i*-C_3H_7CN establishes further **link between** chemical composition of **meteorites and interstellar chemistry**

Chemical composition of protostars with NOEMA

The CALYPSO survey

Continuum And Lines in Young ProtoStellar Objects

- Large Program with IRAM Plateau de Bure interferometer (now NOEMA) + 30 m single-dish telescope for short spacings (PI: Ph. André)

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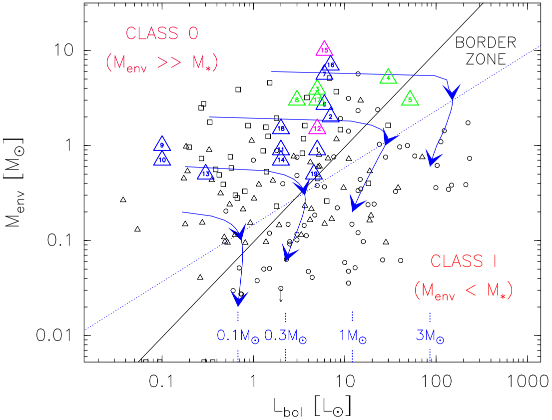
- source sample: 16 of the closest Class 0 protostars ($d < 420$ pc)
- diagnostics: continuum and line observations at ∼100–200 au resolution to derive **physical** and **chemical structure** of **protostellar envelopes**
- strategy: 3 setups (at 1.3, 1.4, and 3 mm) targetting specific molecular lines at high spectral resolution, + **wide-band backends**

Properties of CALYPSO sources



(Courtesy A. Maury, based on André+ 2008, Maury+ 2009)

- sources in Taurus, Perseus, Aquila, Serpens South, and Serpens Main (140–415 pc)
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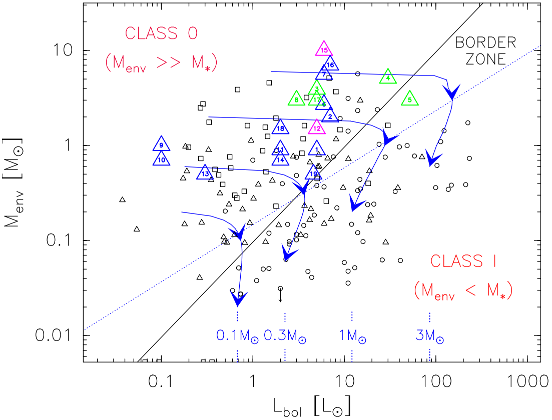

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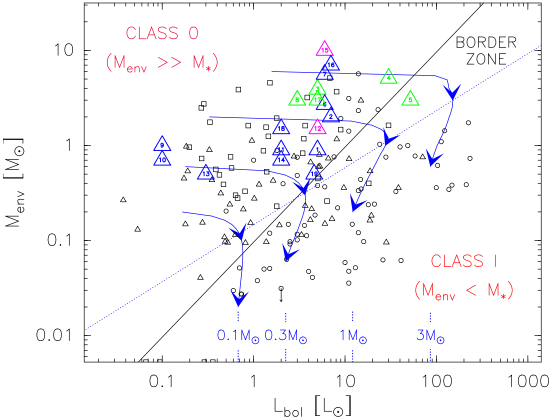

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- a few Class I objects present in some CALYPSO fields

Complex organic molecules in Class 0 protostars

- **presence** of COMs in some Class 0 protostars **well established**
  (e.g., IRAS 16293-2422: Cazaux+ 2003, Jørgensen+ 2016; NGC 1333-IRAS4A/4B/2A: Bottinelli+ 2004, 2007)

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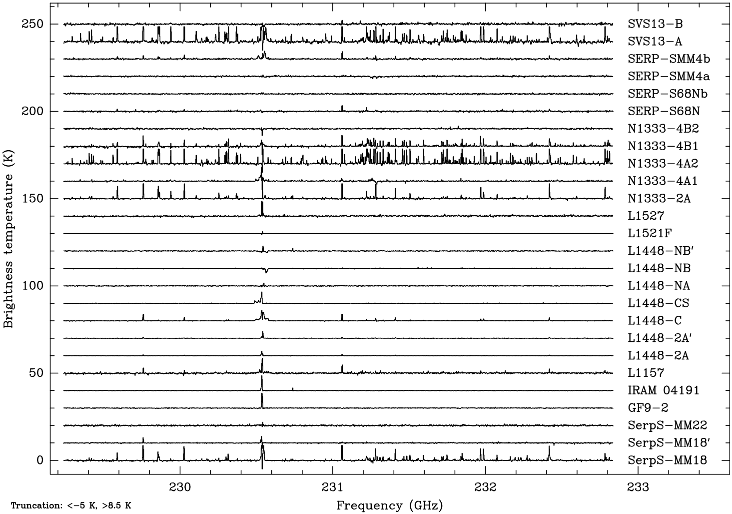
$\Rightarrow$ CALYPSO survey well suited to explore origin of COMs in Class 0 protostars **on a statistical basis**

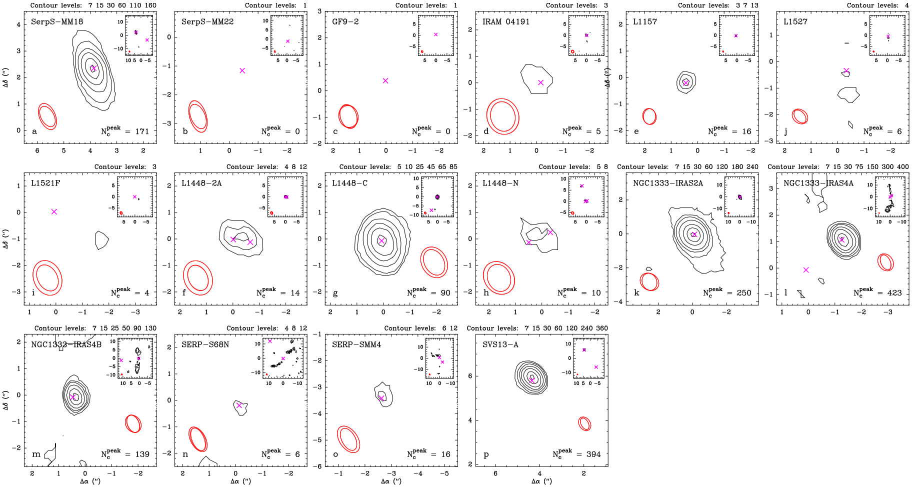
NOEMA spectra of Calypso sources



COMs in Calypso sources: line counts

Maps of number of channels with line emission above 6σ (δv~2.6 km s^{-1})

(within 216.8–220.5 and 229.2–232.8 GHz, excluding CO, ^{13}CO, C^{18}O, SiO, SO, OCS)



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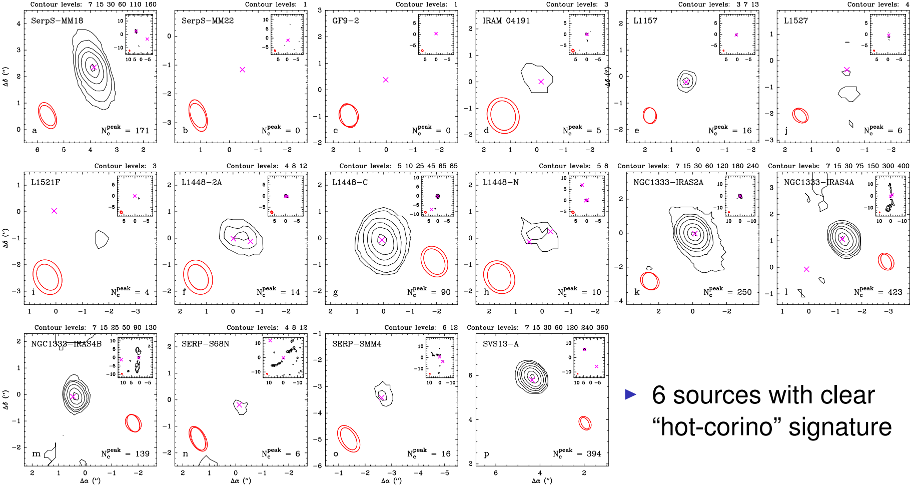

- 6 sources with clear “hot-corino” signature

COM composition of CALYPSO sources

Three types of COM composition?

Correlations between COMs

- whatever type of normalization, correlation found for:
  CH_3CN & CH_3OCH_3,
  CH_3CN & CH_3OH,
  NH_2CHO & CH_3OH,
  CH_3CHO & CH_3OCHO
  ...

⇒ correlation does **not** imply chemical link between species!

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⇒ chemical complexity reduced when UV radiation stronger?

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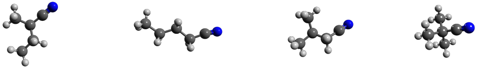

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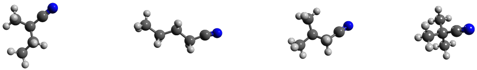

Exploring molecular complexity: how to beat the confusion limit?

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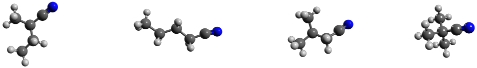

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- go to lower frequencies: ALMA bands 1 and 2, ngVLA, SKA?
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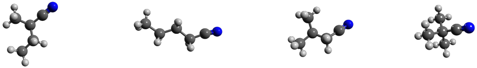

Exploring molecular complexity: how to beat the confusion limit?

- go to lower frequencies: ALMA bands 1 and 2, ngVLA, SKA?
  (see also PRIMOS spectral survey of Sgr B2(N) with GBT, PI: A. Remijan)
- target sources with narrower linewidths
  (see, e.g., PILS spectral survey of hot corino IRAS 16293-2422 with ALMA, PI: J. Jørgensen; detection of CH_3OCH_2OH in NGC 6334I-MM1, McGuire+ 2017)