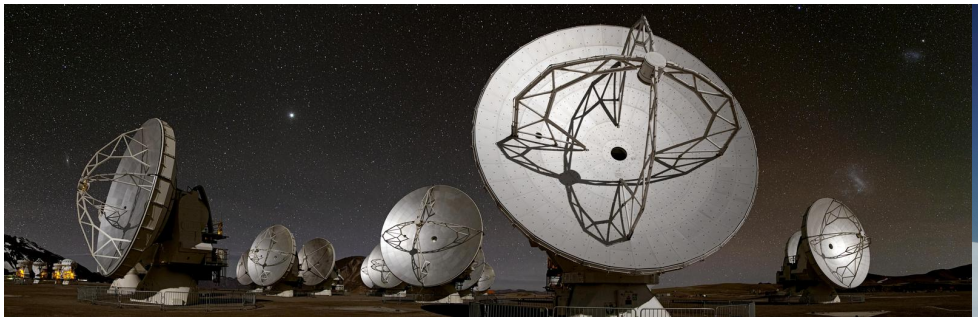

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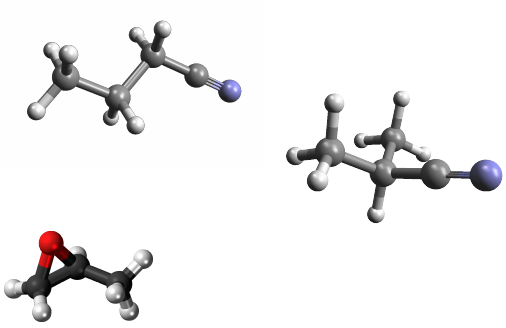
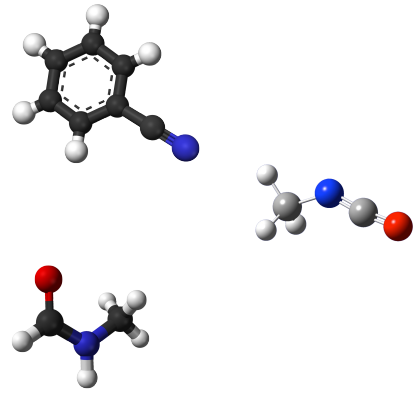
Molecular complexity in the interstellar medium

Arnaud Belloche

Max-Planck-Institut für Radioastronomie

Bonn, Germany





XIVth Rencontres du Vietnam

The Cosmic Cycle of Dust and Gas in the Galaxy:

From Old to Young Stars

Quy Nhon, Vietnam

12 July 2018

Max-Planck-Institut für Radioastronomie

CALYPSO

SFB 956 Cologne | Bonn

MAX-PLANCK-GESELLSCHAFT

Complex organic molecules in the ISM

Growing complexity of interstellar molecules

Chemical composition of protostars

Outlook

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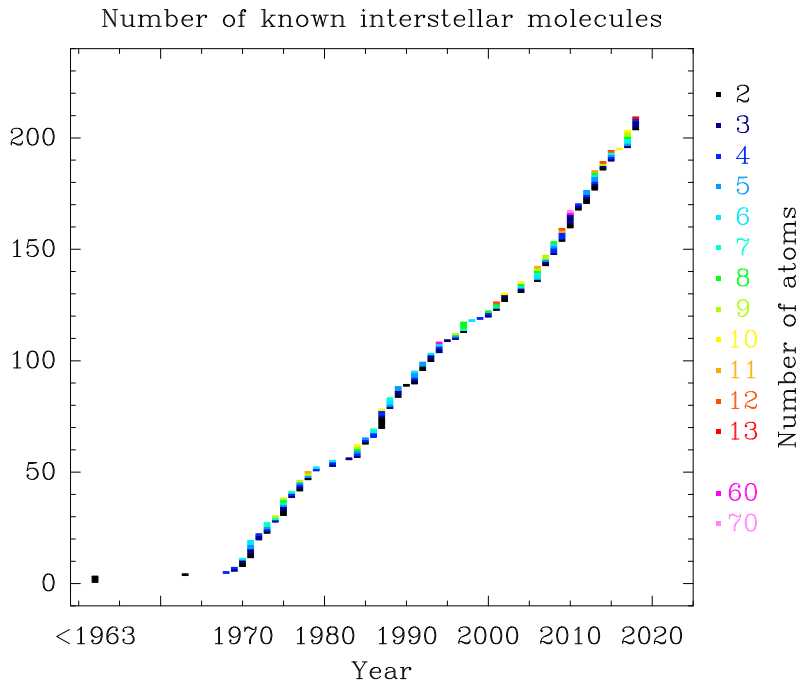
$\Rightarrow$ is molecular complexity of comets/meteorites a **widespread** outcome of interstellar chemistry? What is the degree of **chemical complexity** in the ISM?

Molecules in the interstellar medium



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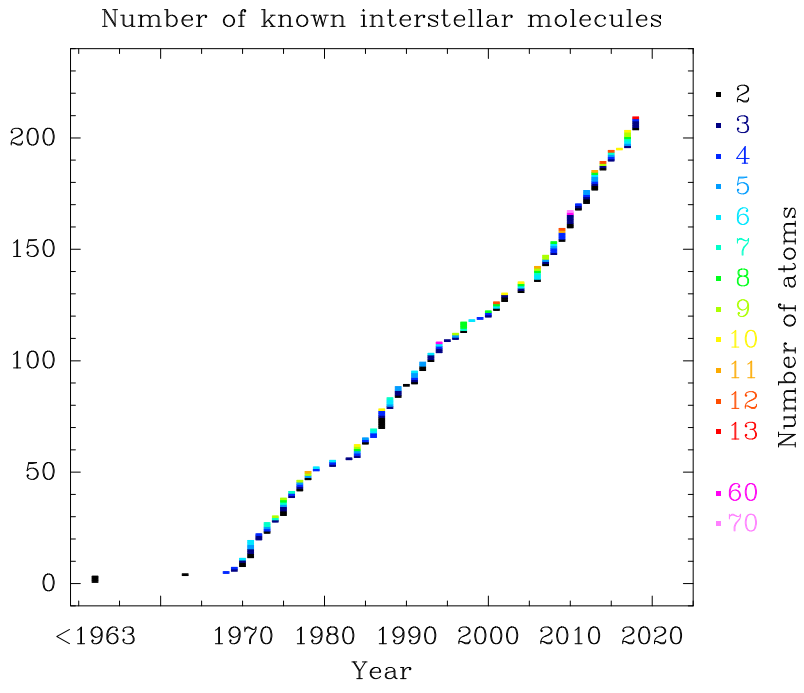

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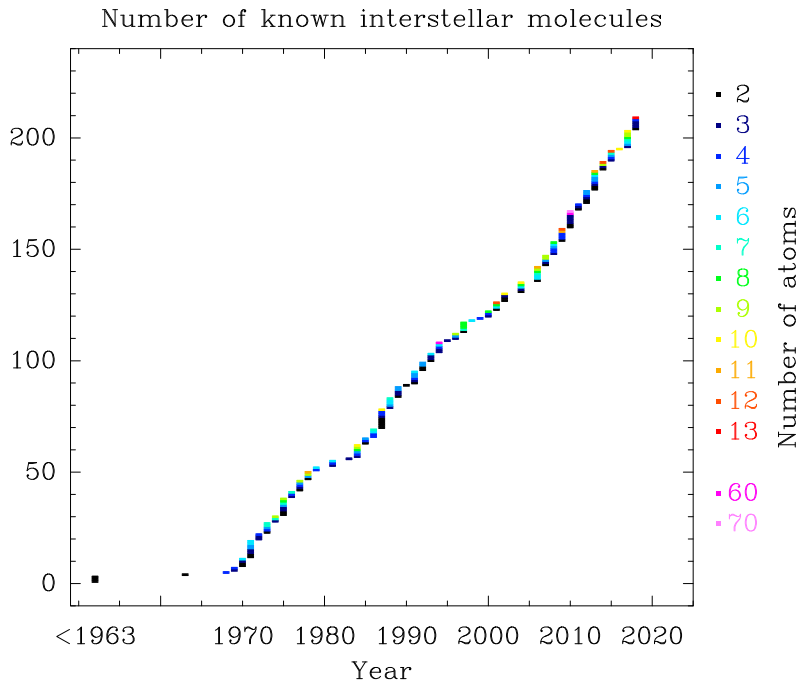

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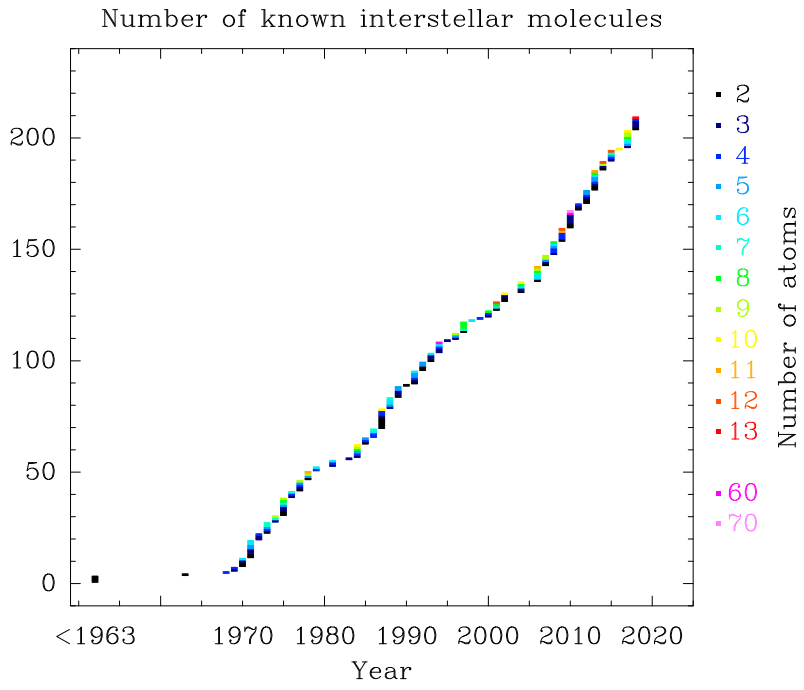

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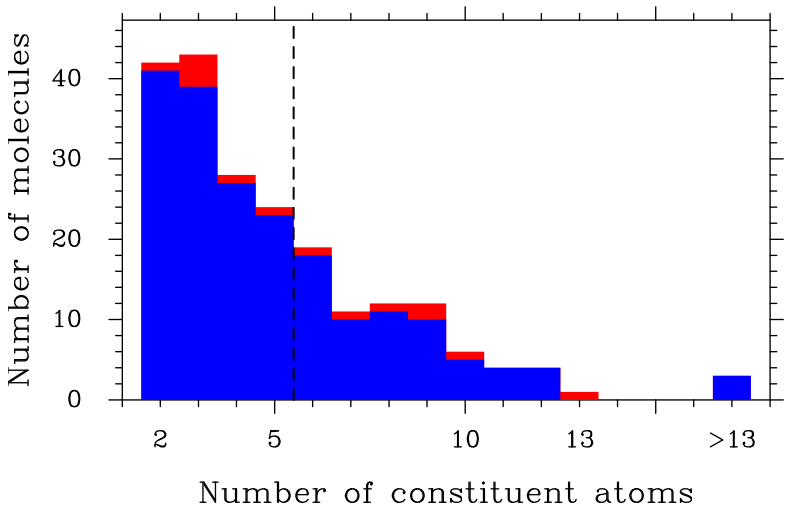

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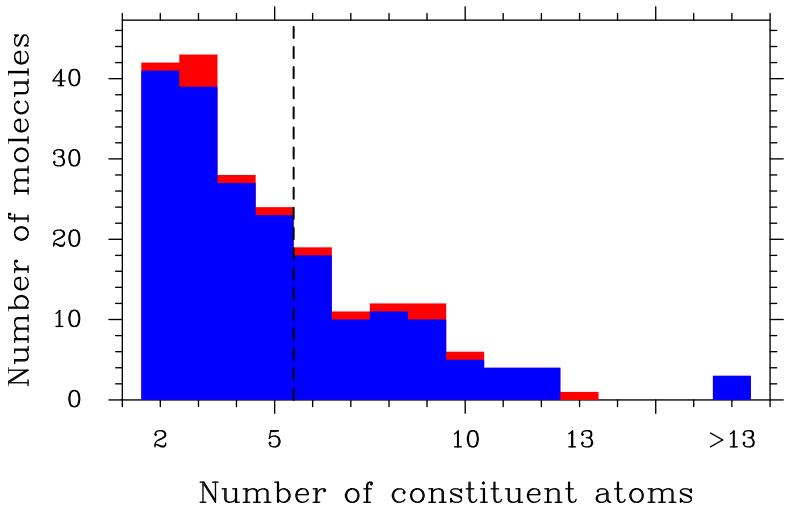

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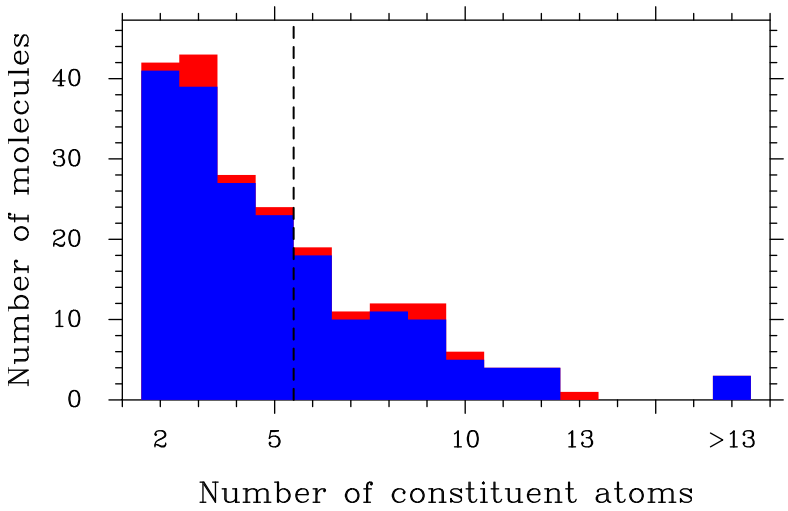

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⇒ **where** are COMs found in the interstellar medium?

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$\Rightarrow$ interplay between **observations**, astrochemical **modeling**, and **experiments**

Growing complexity of interstellar molecules

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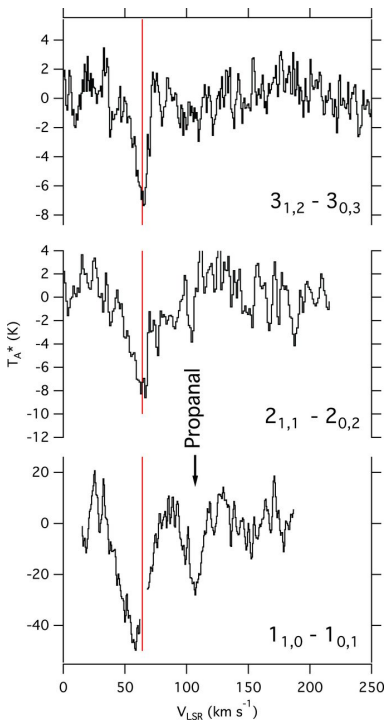

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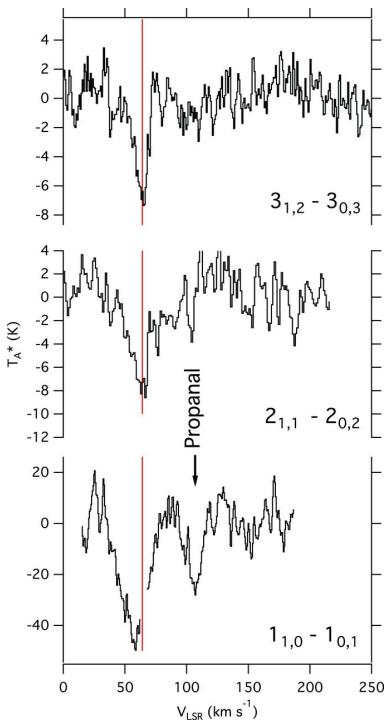

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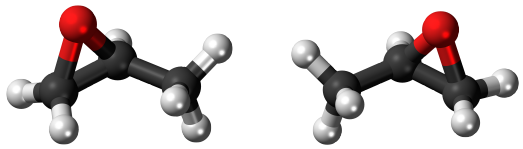

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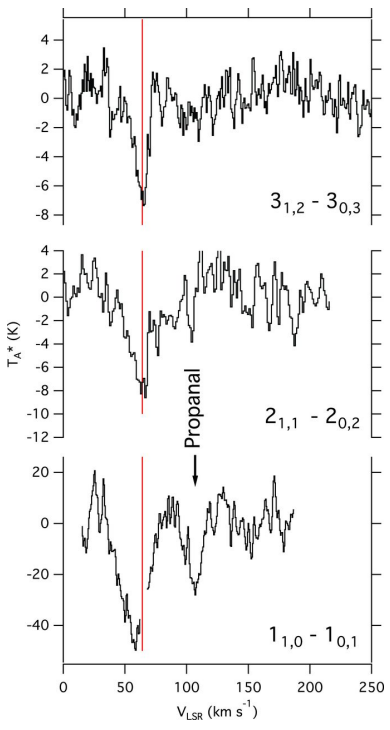

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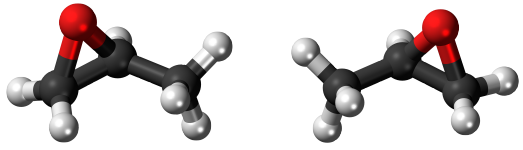

- other chiral molecules? deuterated ethyl cyanide CH_3CHDCN tentatively detected (with ALMA; Belloche+ 2016); 2-aminopropionitrile $CH_3CH(NH_2)CN$ not detected (neither IRAM 30 m telescope nor ALMA; Møllendal+ 2012, Richard+ 2018)

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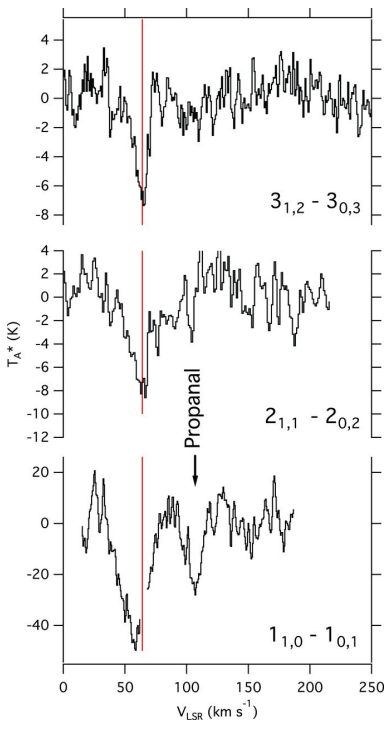

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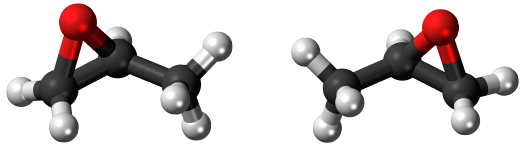

- other chiral molecules? deuterated ethyl cyanide CH_3CHDCN tentatively detected (with ALMA; Belloche+ 2016); 2-aminopropionitrile $CH_3CH(NH_2)CN$ not detected (neither IRAM 30 m telescope nor ALMA; Møllendal+ 2012, Richard+ 2018)
- can an enantiomeric excess in the ISM be measured? Possibly via **circular dichroism** (see discussion in McGuire+ 2016)

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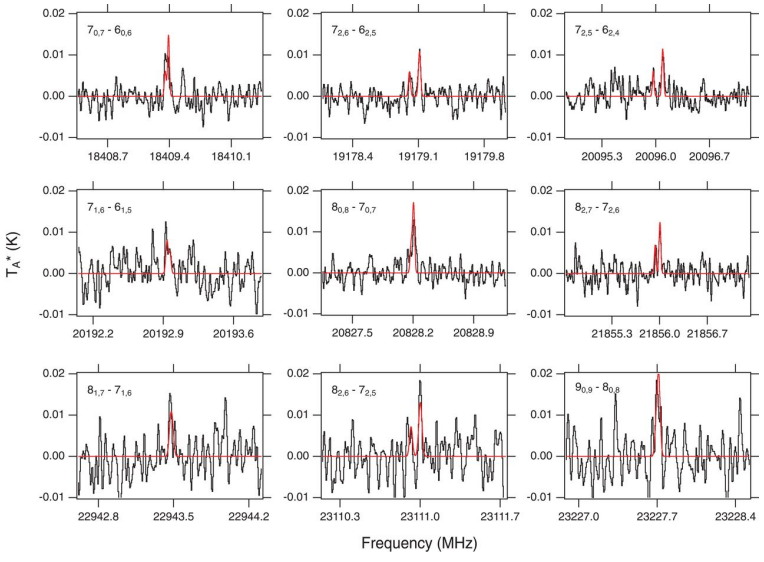

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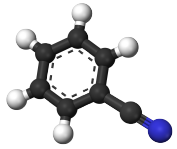

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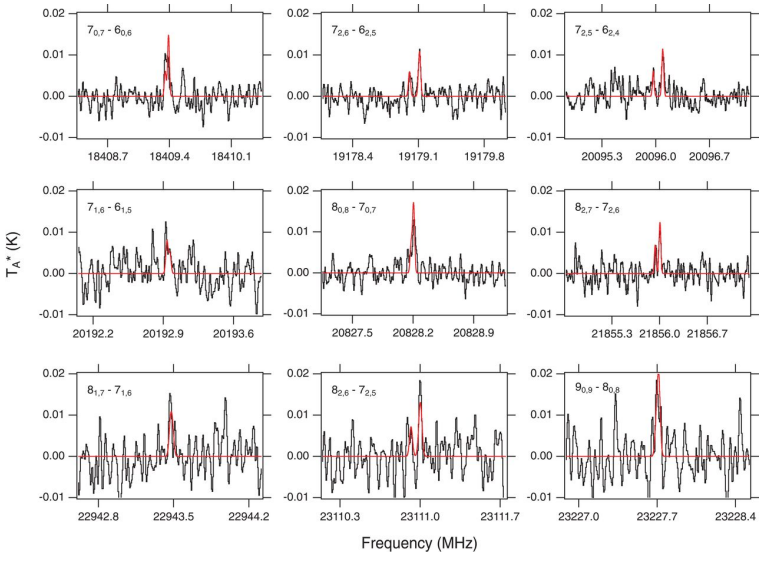

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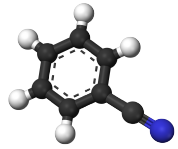

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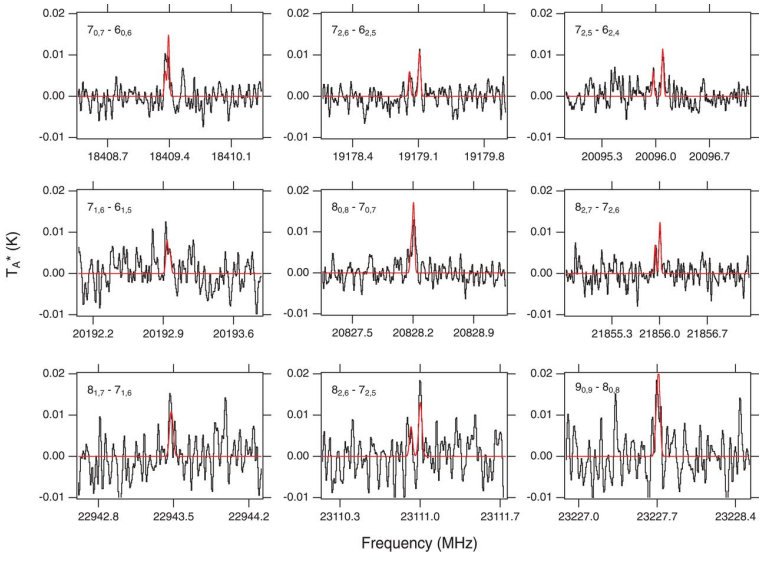

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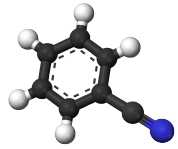

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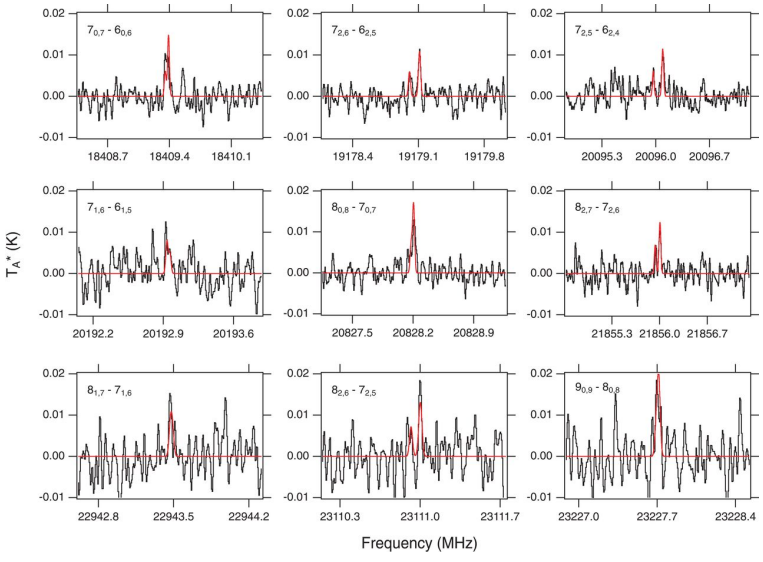

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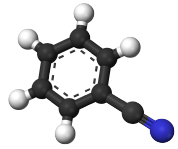

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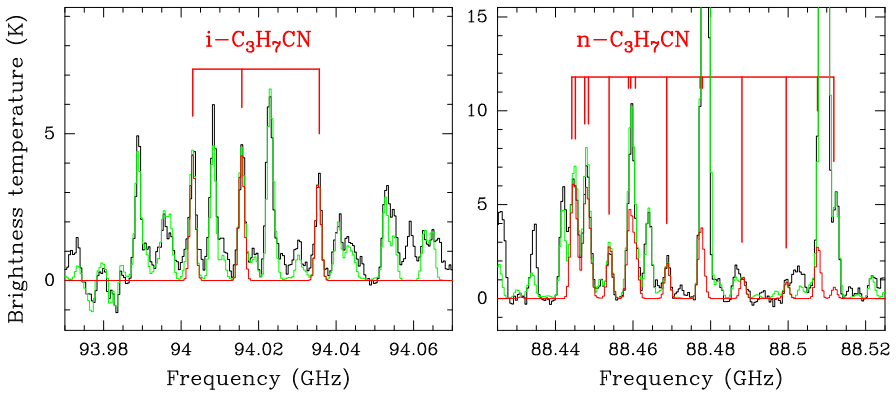
- benzonitrile precursor to polyaromatic species? (bottom-up process)

Branched molecules

(Belloche et al. 2014, Science, 345, 1584; Garrod et al. 2017, A&A, 601, A48)



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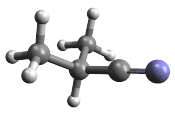

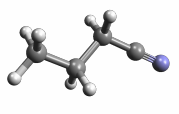

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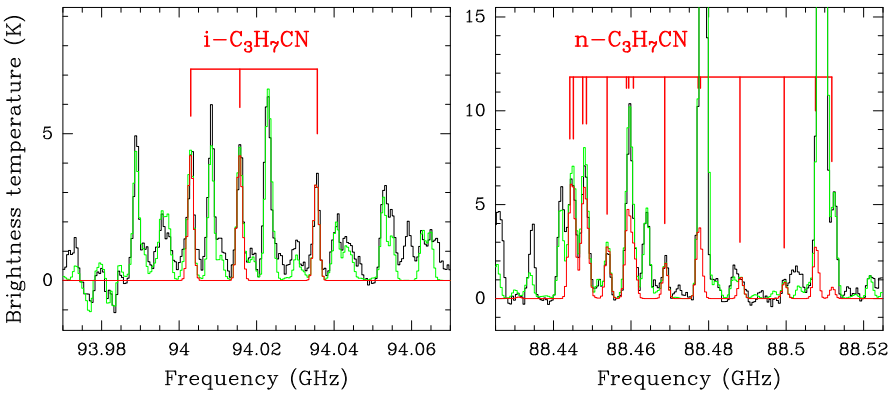

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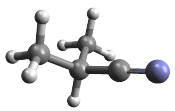

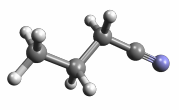

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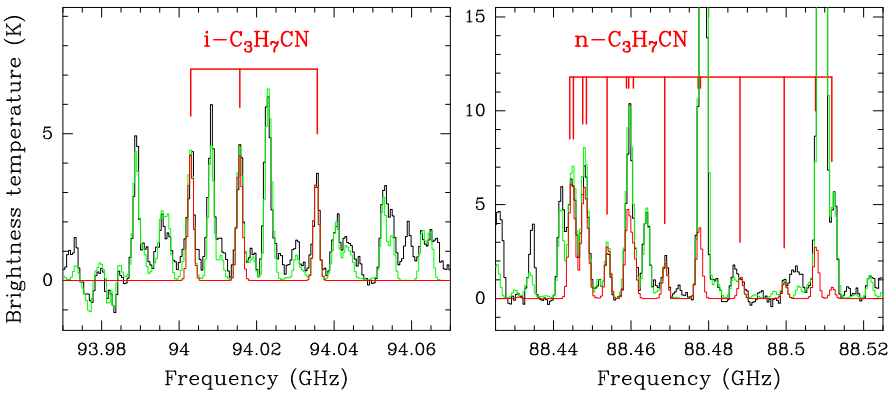

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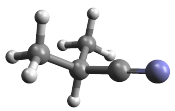

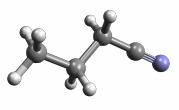

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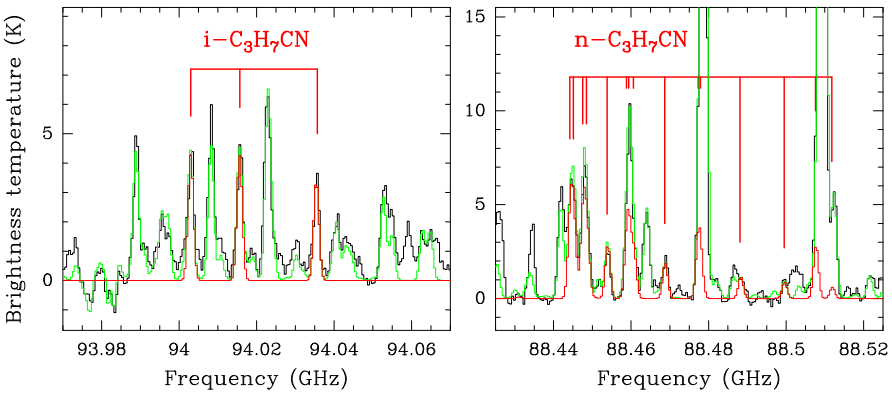

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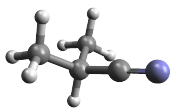

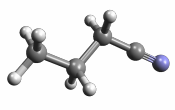

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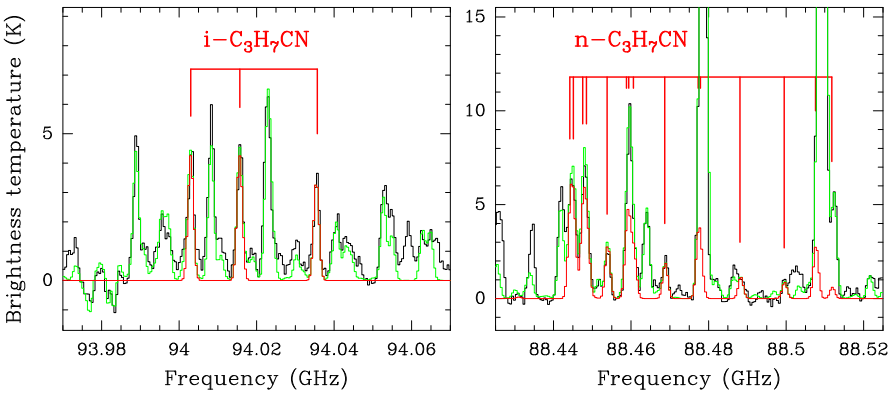

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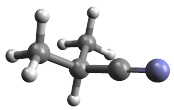

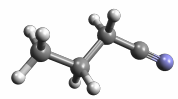

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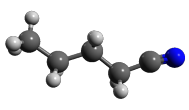
⇒ detection of *i*-C_3H_7CN establishes further **link between** chemical composition of **meteorites and interstellar chemistry**

Do branched molecules dominate in the ISM?



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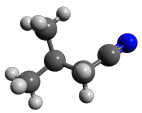

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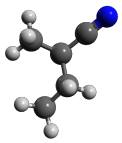

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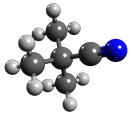

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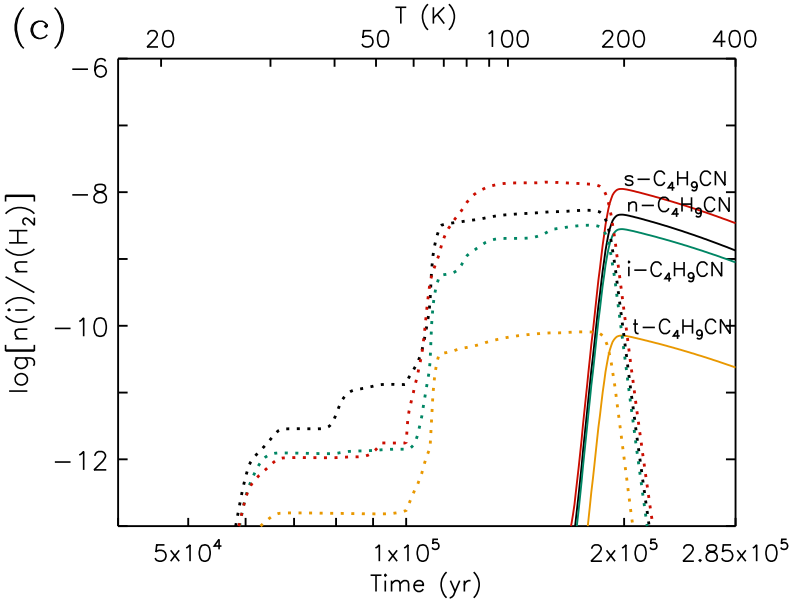

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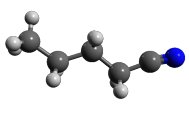

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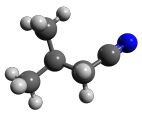

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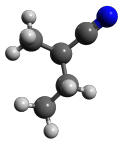

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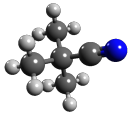

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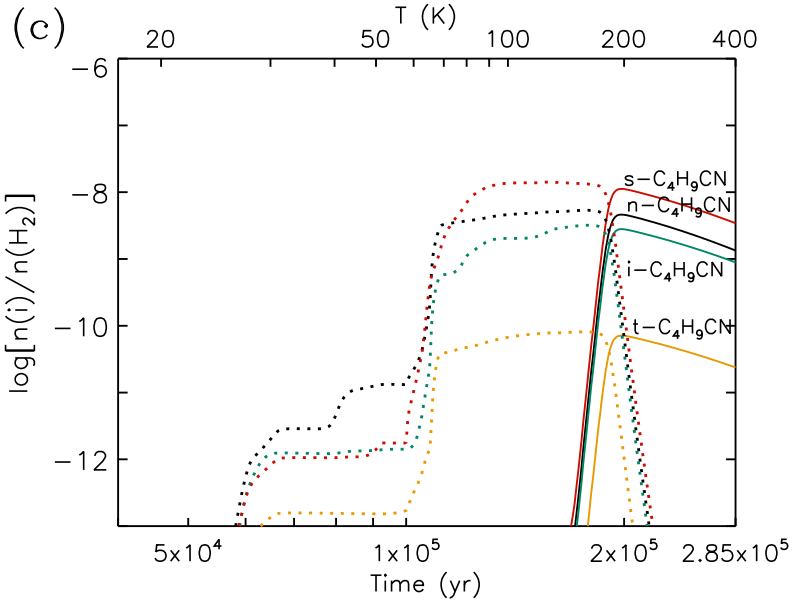

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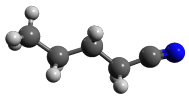

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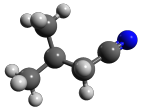

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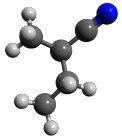

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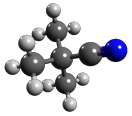

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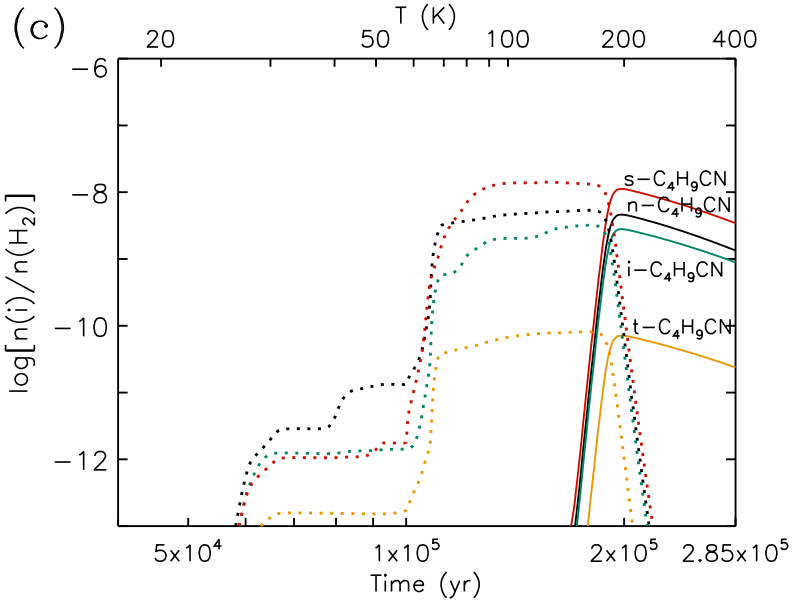

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  - on-going Cycle 4 project targetting Sgr B2(N), follow-up of EMoCA

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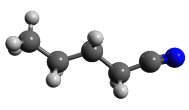

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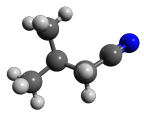

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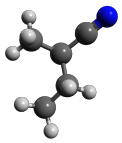

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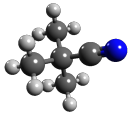

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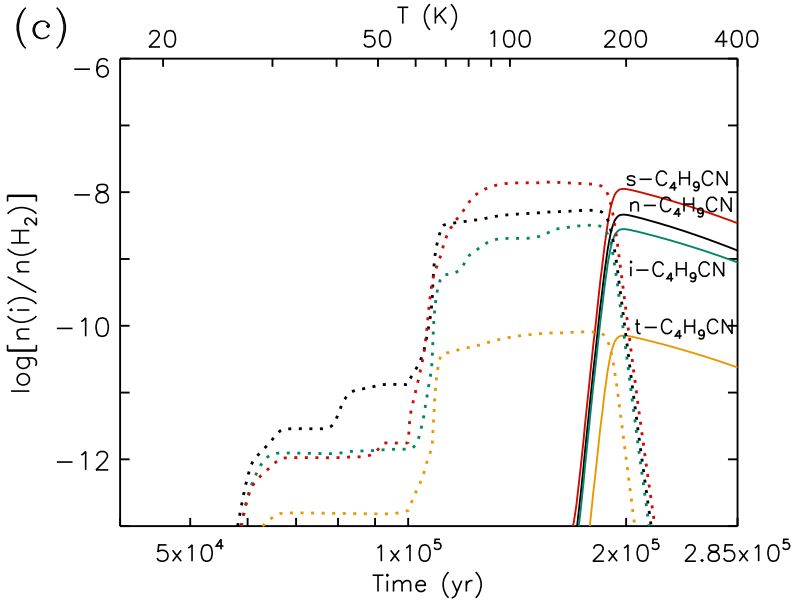

Garrod+ 2017

- model predicts that **branched isomers** of butyl cyanide (C_4H_9CN) should **dominate** over straight-chain form in Sgr B2

  ⇒ **observational test**: search for butyl cyanide with ALMA!

  - lab. spectroscopy done in Cologne (Ordu+ 2012, Müller+ 2017, Wehres+ 2018)
  - on-going Cycle 4 project targetting Sgr B2(N), follow-up of EMoCA

Chemical composition of protostars

Complex organic molecules in Class 0 protostars

- **presence** of COMs in some Class 0 protostars **well established**
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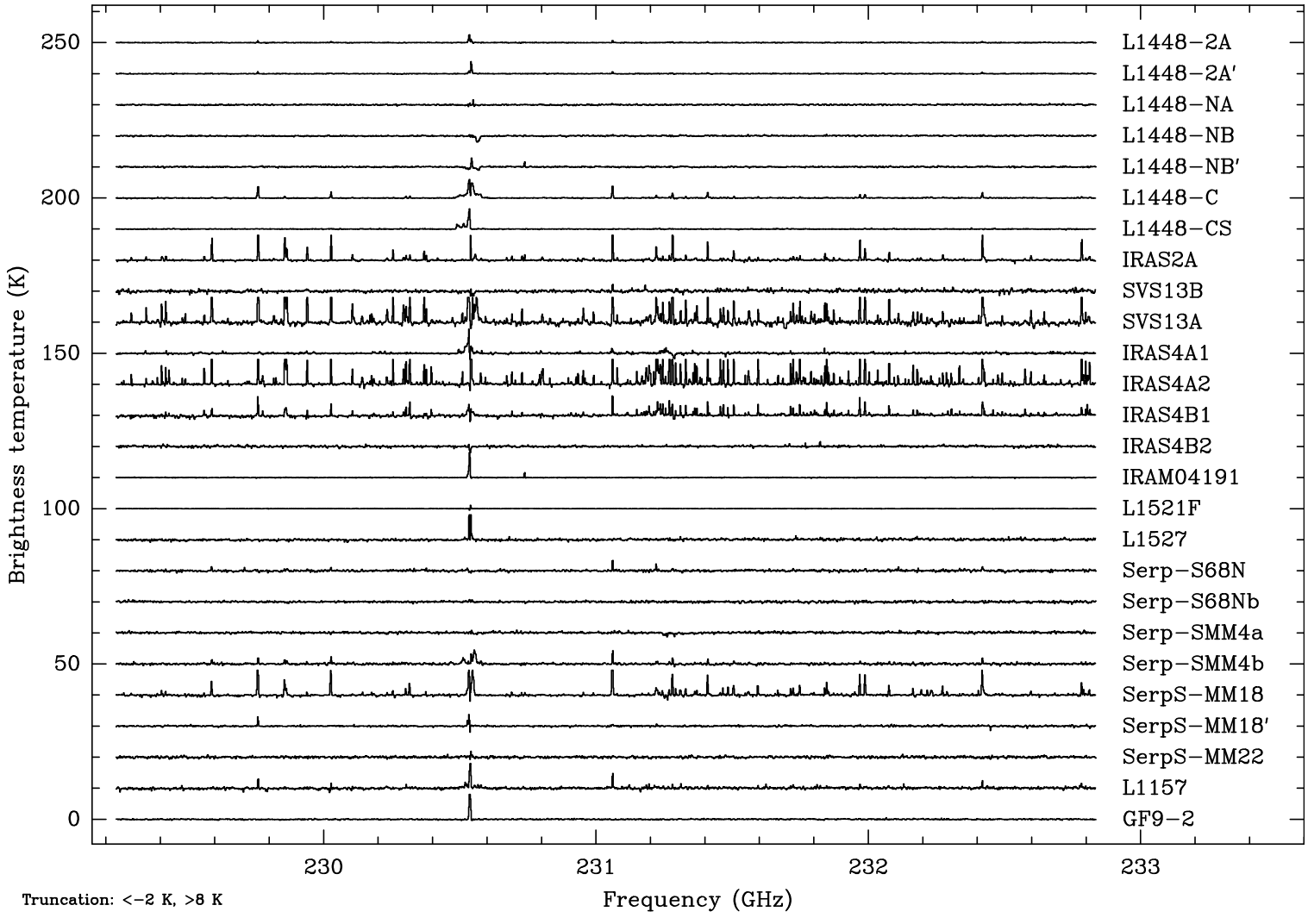
$\Rightarrow$ **CALYPSO survey** (Continuum and Line in Young ProtoStellar Objects) well suited:

- Large Program with NOEMA (100–200 au resolution; PI: Ph. André)
- source sample: 16 of the closest Class 0 protostars ($d < 420$ pc)

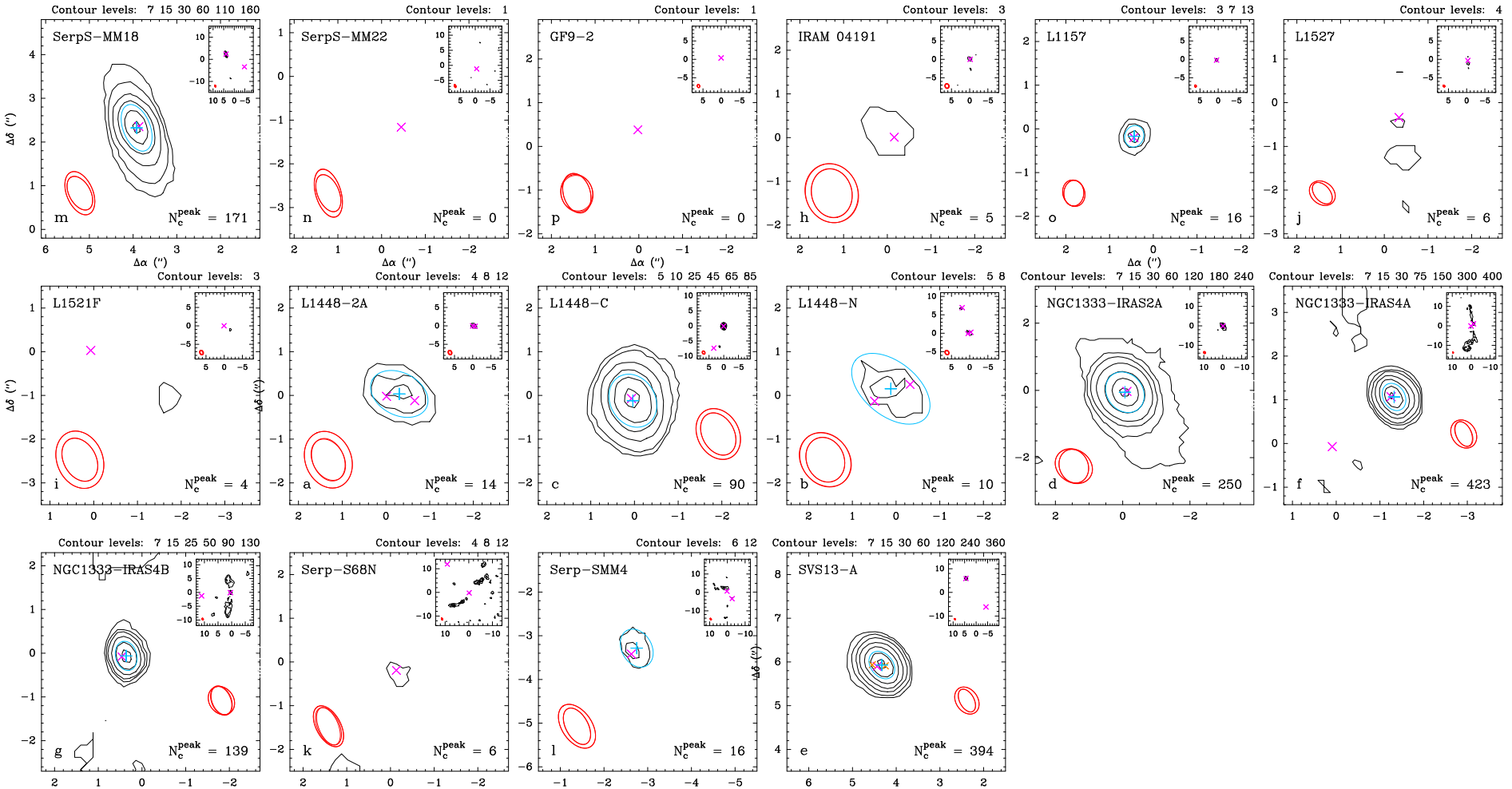
NOEMA spectra of Calypso sources



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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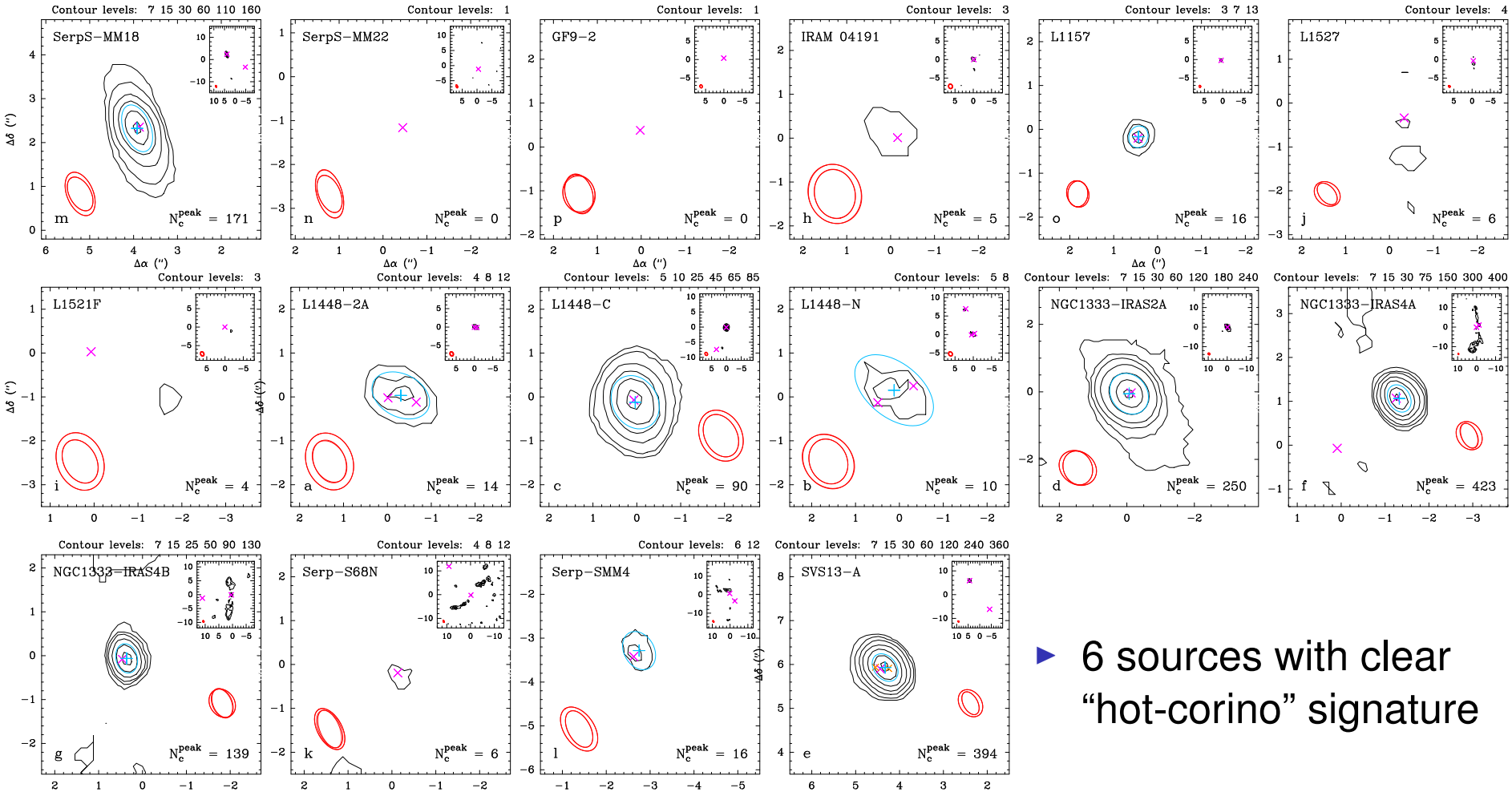

- 6 sources with clear “hot-corino” signature

COM composition of CALYPSO sources

Three types of COM composition?

Correlations between COMs

- 95% confidence interval of Pearson correlation coefficient

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

$\Rightarrow$ correlation does **not** imply chemical link between species!

Correlation with source properties?

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$\Rightarrow$ chemical complexity reduced when UV radiation stronger?

(but is there significant UV flux at these scales?)

Outlook

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COMs in Class 0 protostars

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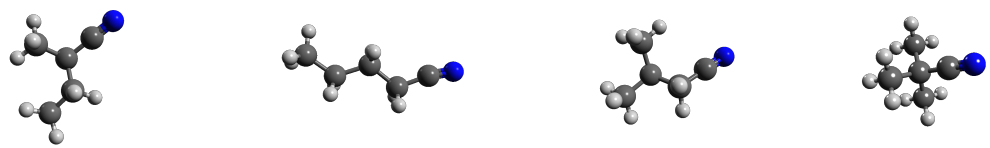
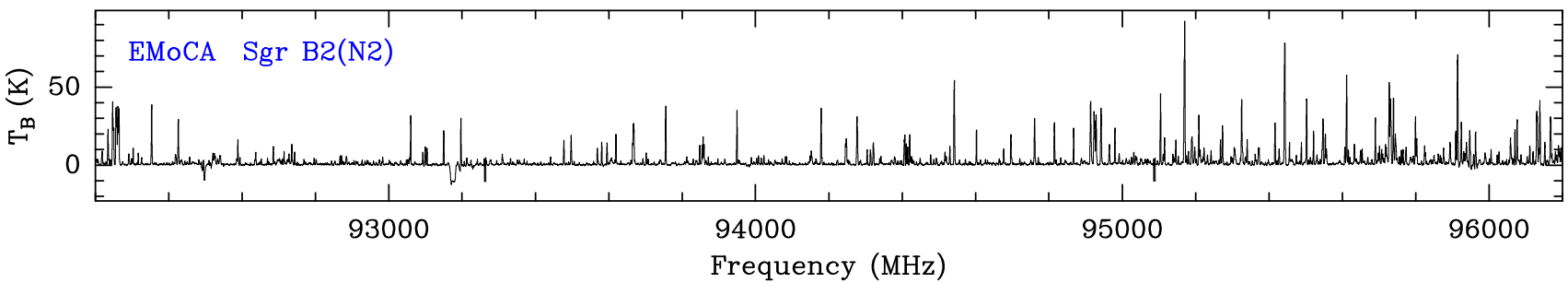
  → test of model predictions with ALMA: on-going search for C_4H_9CN (4 isomers)



Outlook (2)

Exploring molecular complexity: how to beat the confusion limit?



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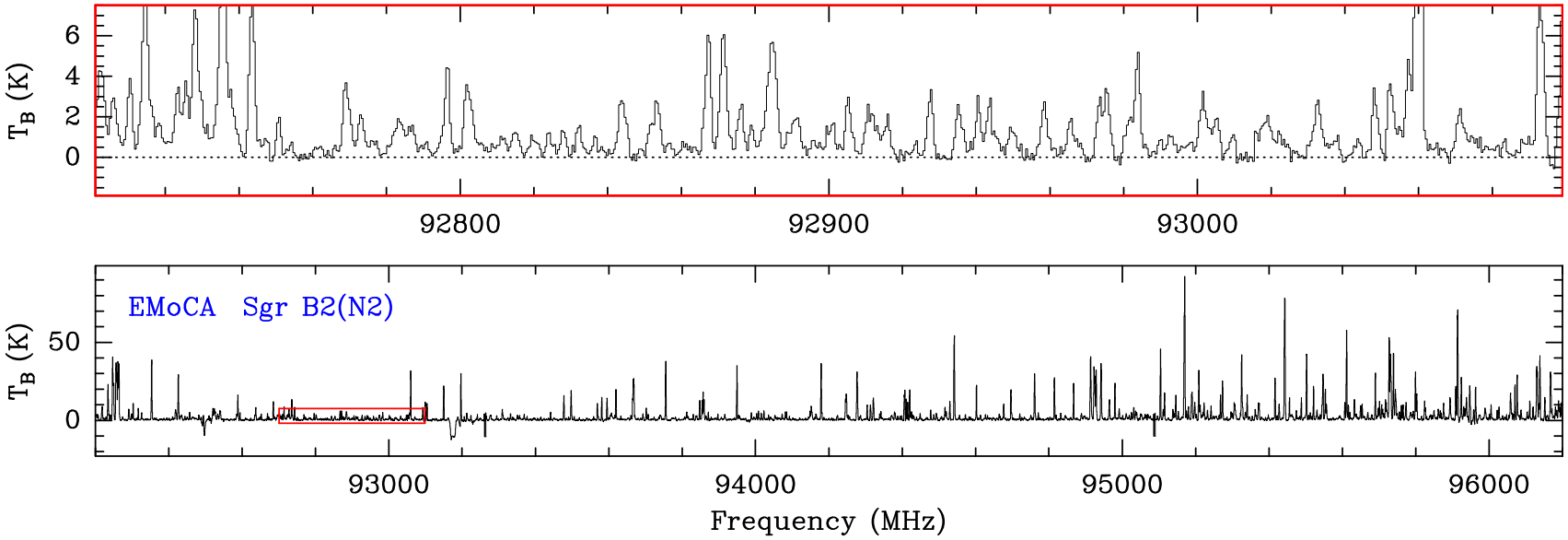

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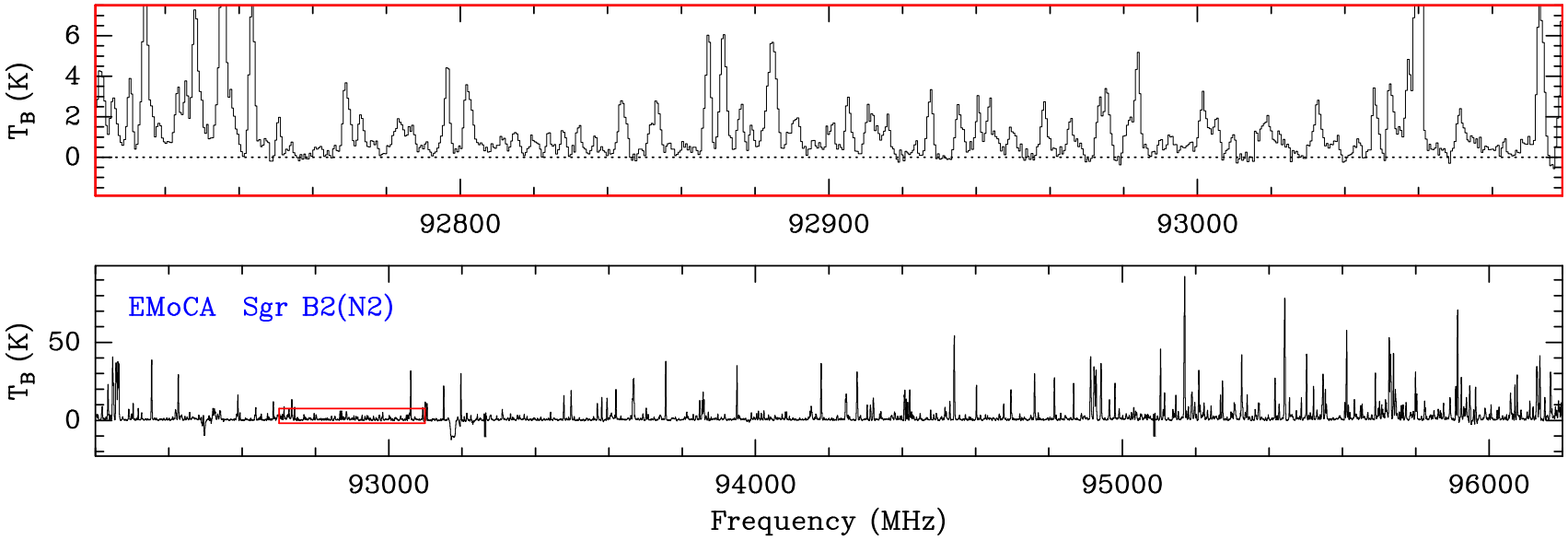

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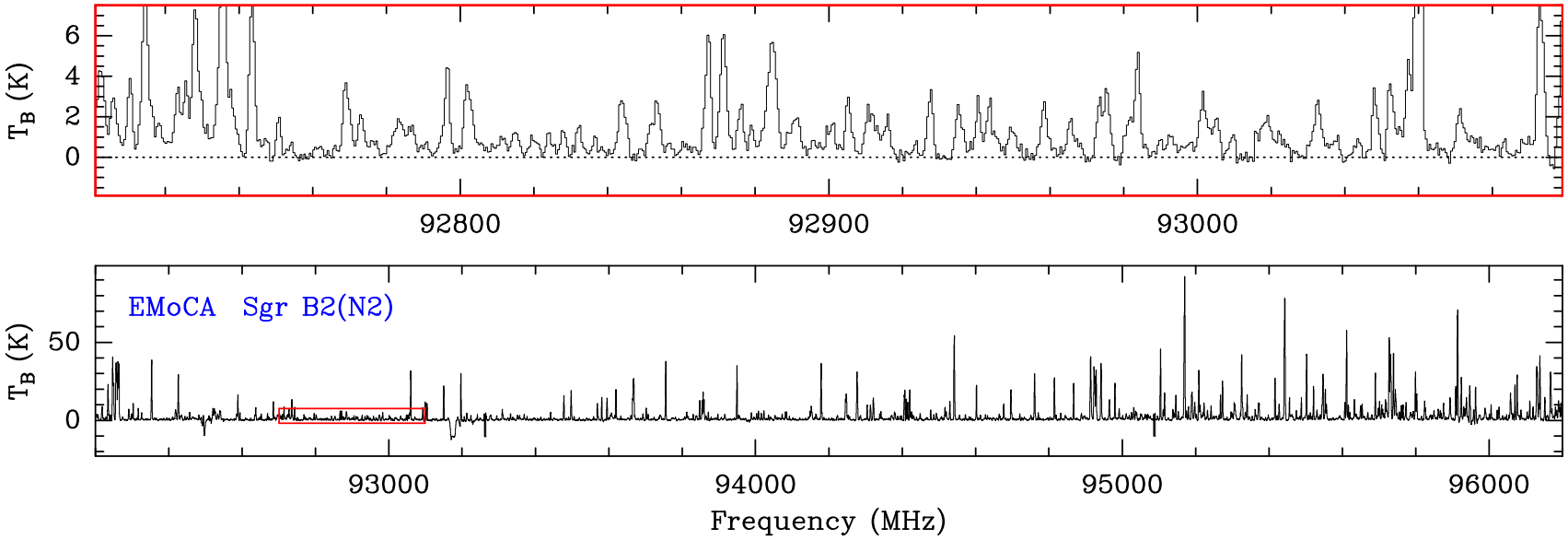

- go to lower frequencies: ALMA bands 1 and 2, ngVLA, SKA?
  (see also PRIMOS spectral survey of Sgr B2(N) with GBT, PI: A. Remijan)
- target sources with narrower linewidths
  (see, e.g., PILS spectral survey of hot corino IRAS 16293-2422 with ALMA, PI: J. Jørgensen; detection of CH_3OCH_2OH in NGC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