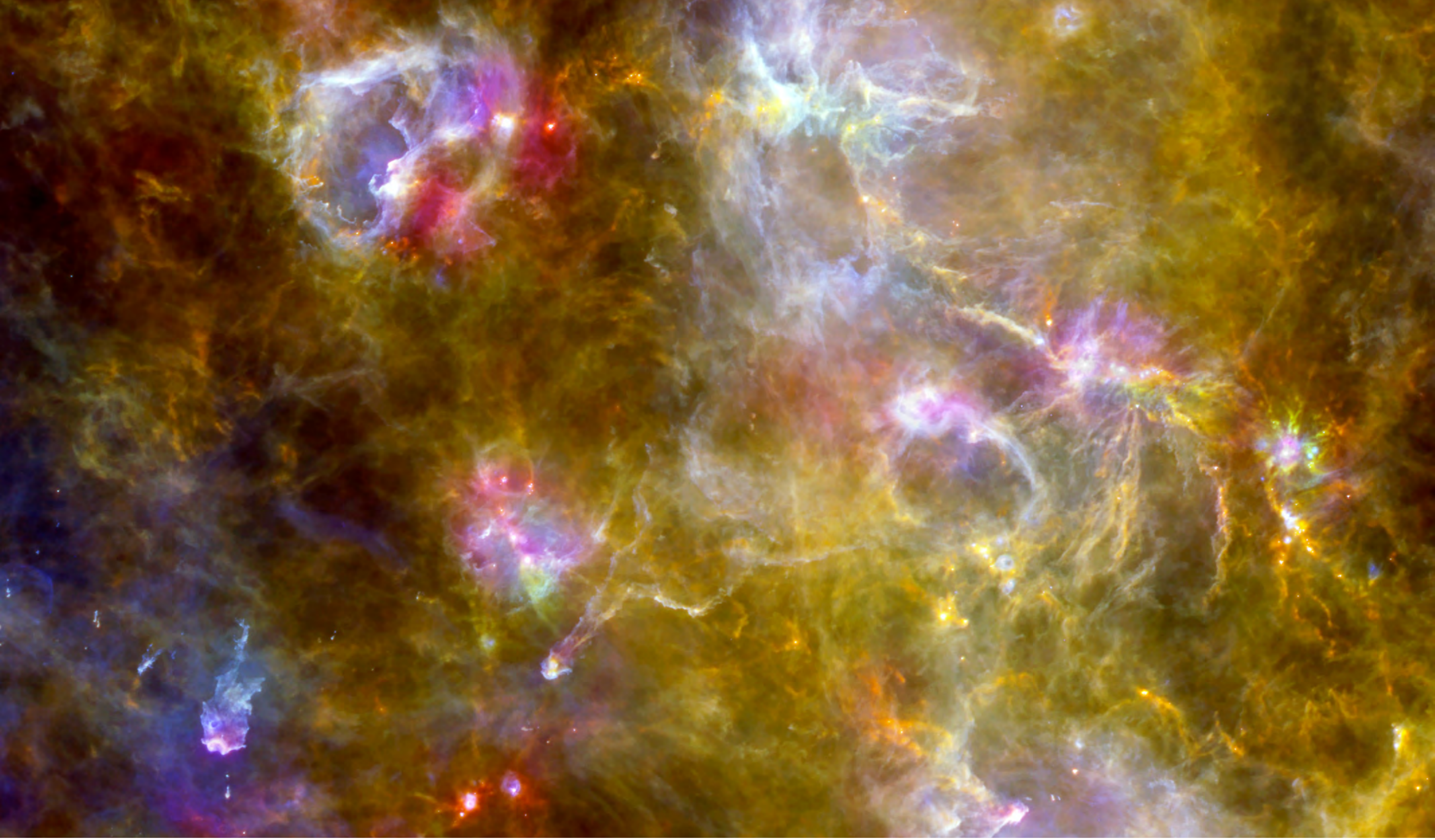
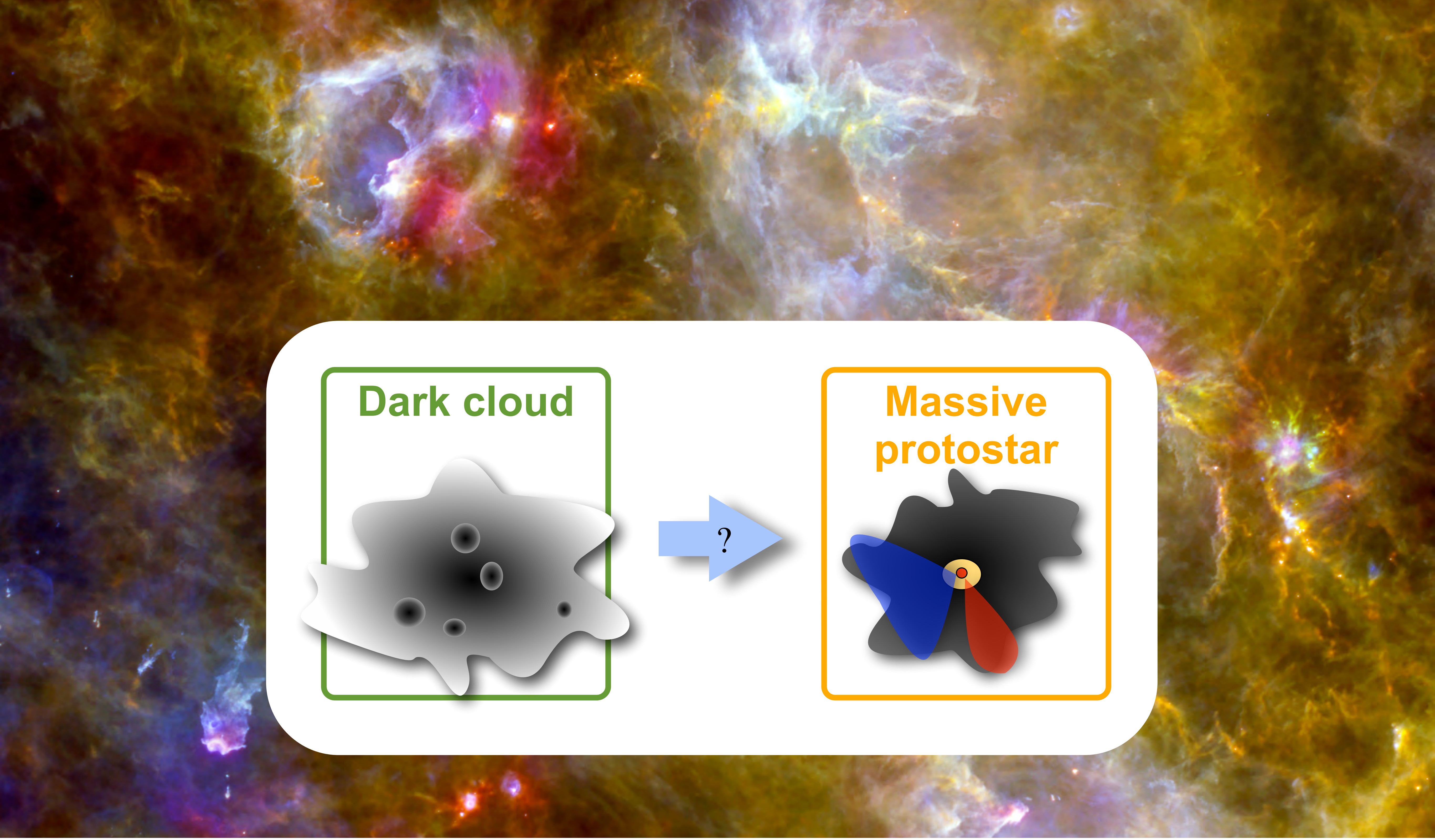


The **astrochemical link** between dark clouds and hot cores ?

Sarah Fechtenbaum

Star Formation meeting
03/10/15

université de BORDEAUX
LAB



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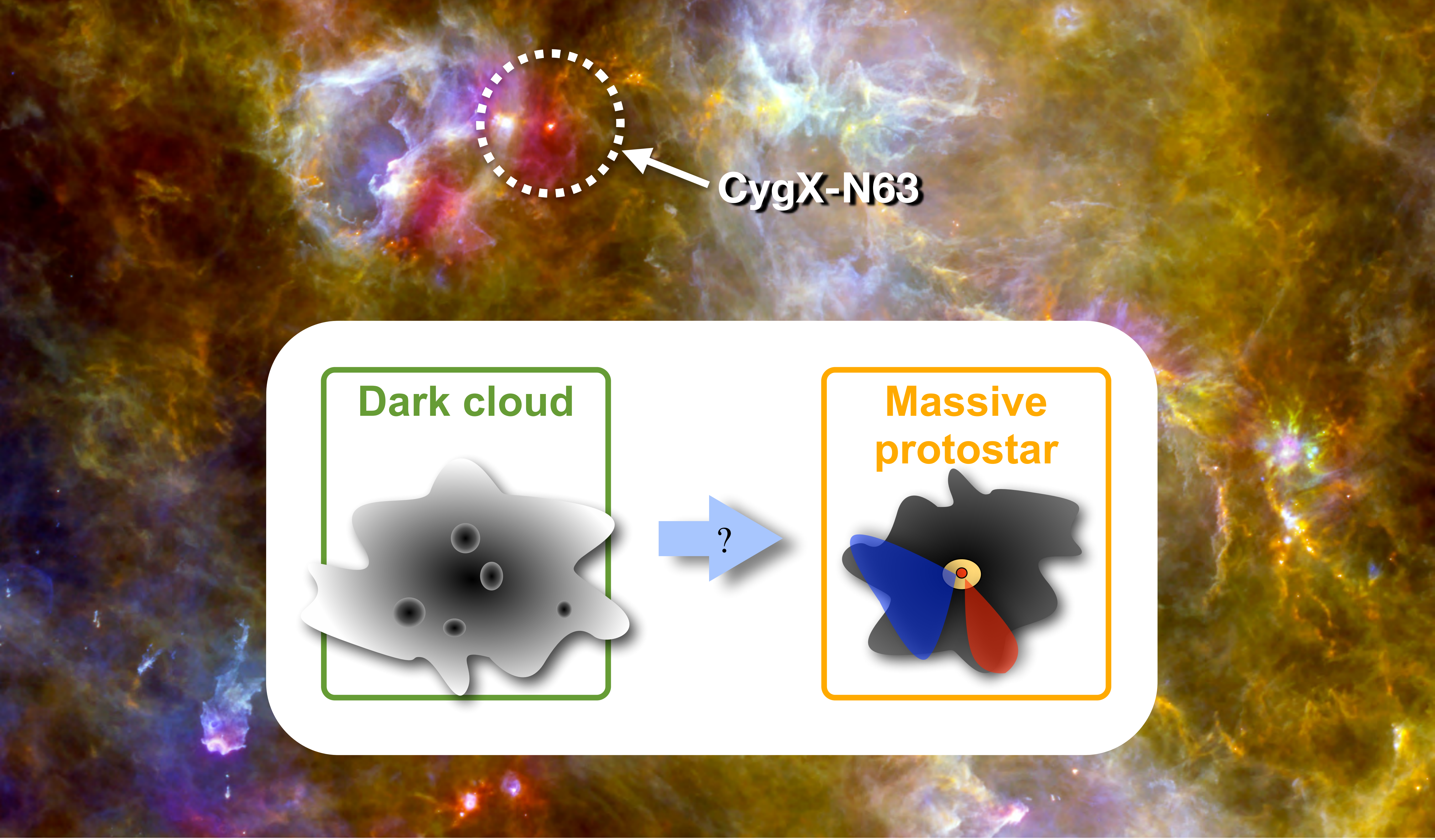

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CygX-N63: a lovely protostar

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Found by Motte et al. 2007

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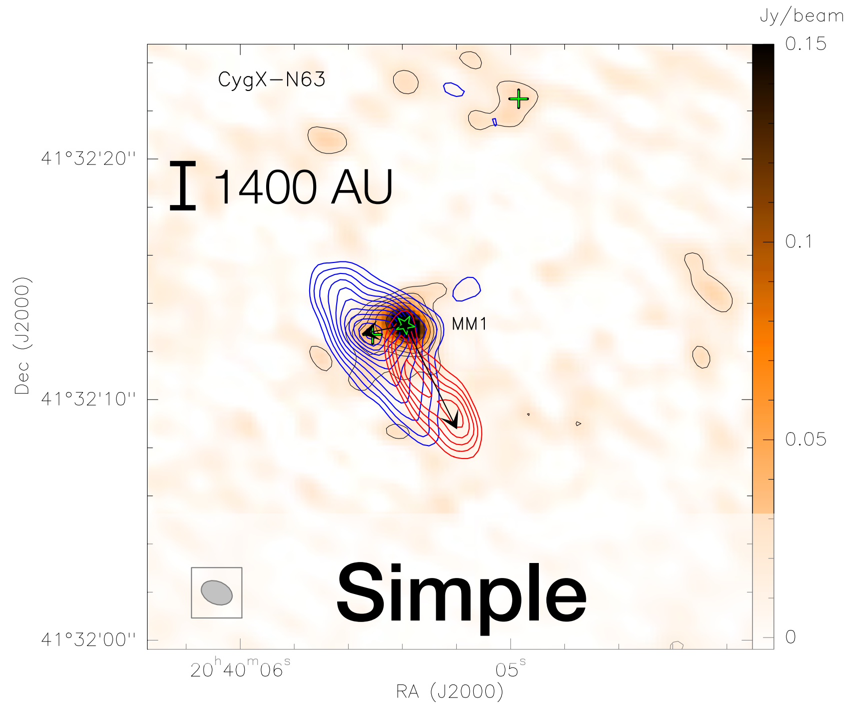

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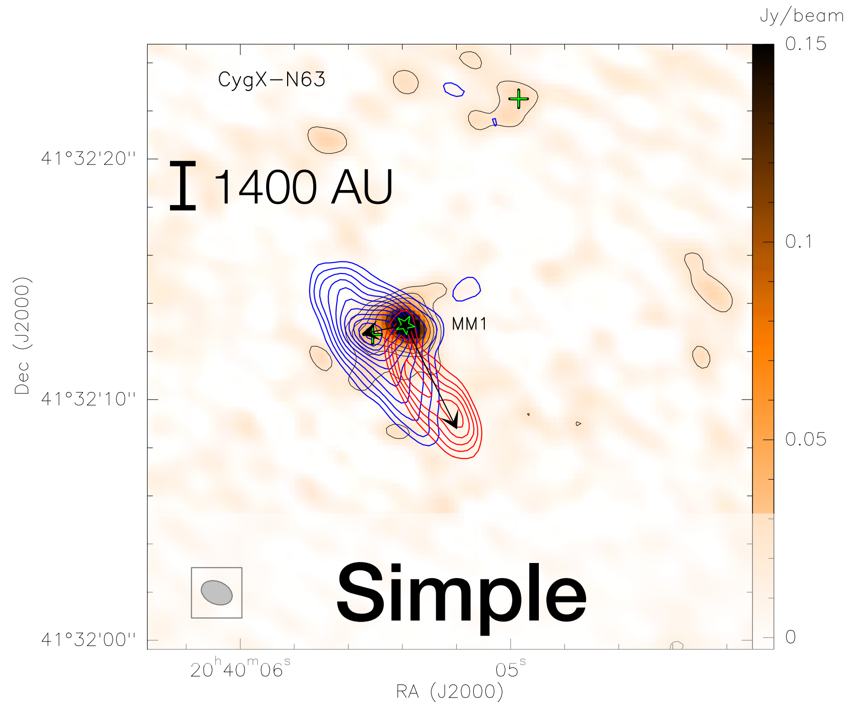

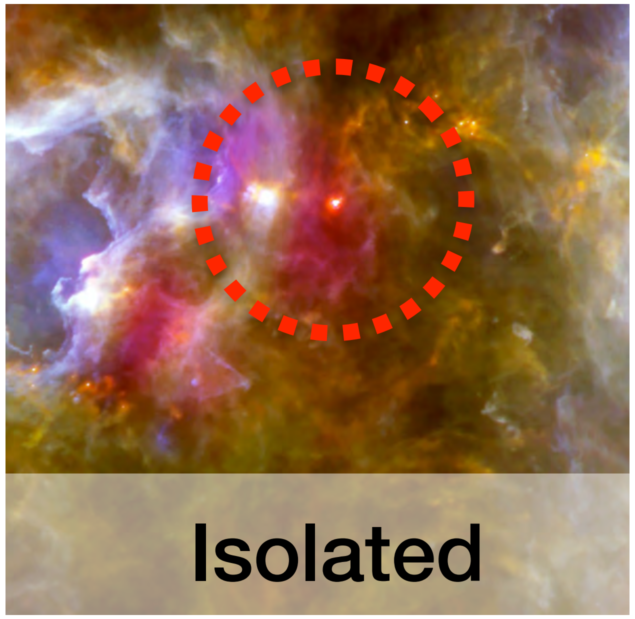

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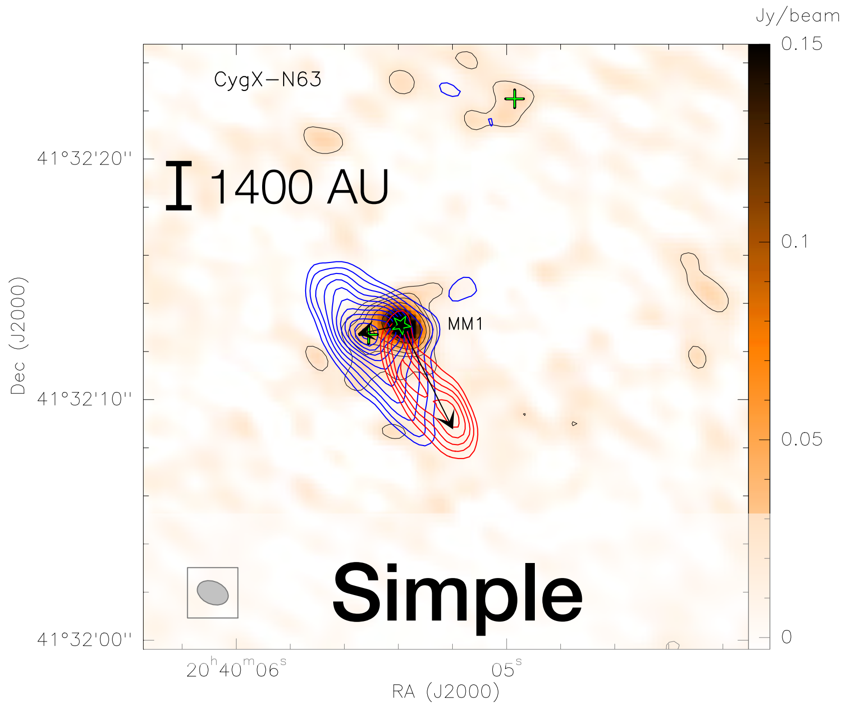

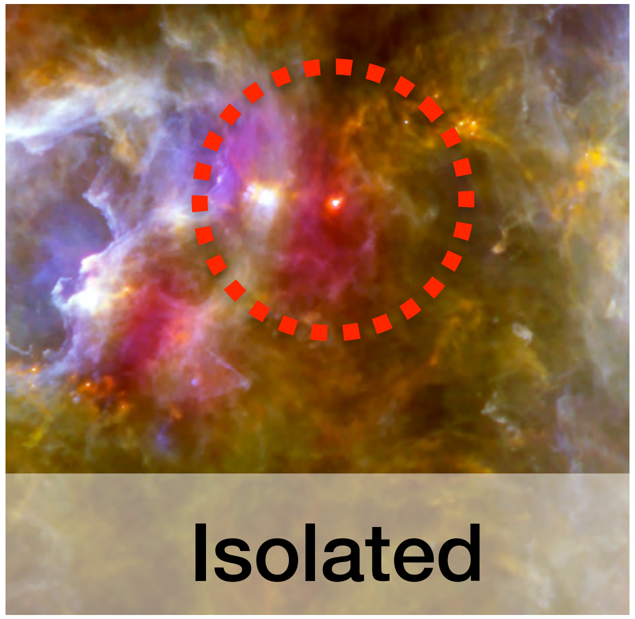

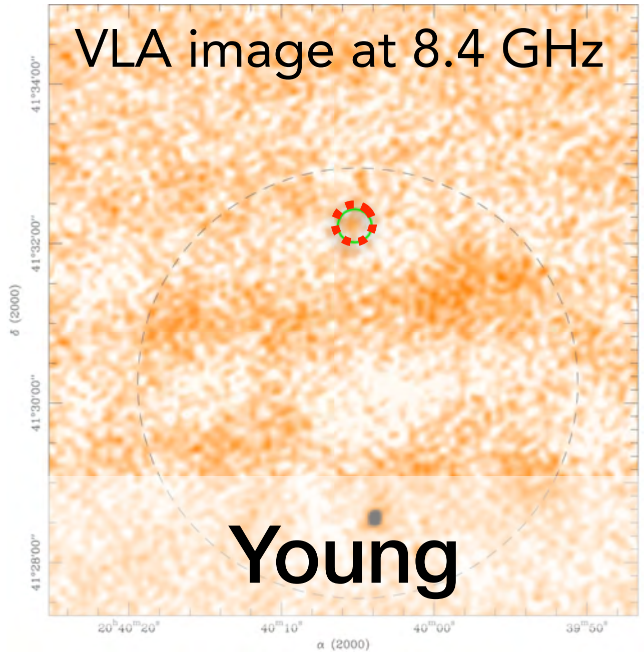

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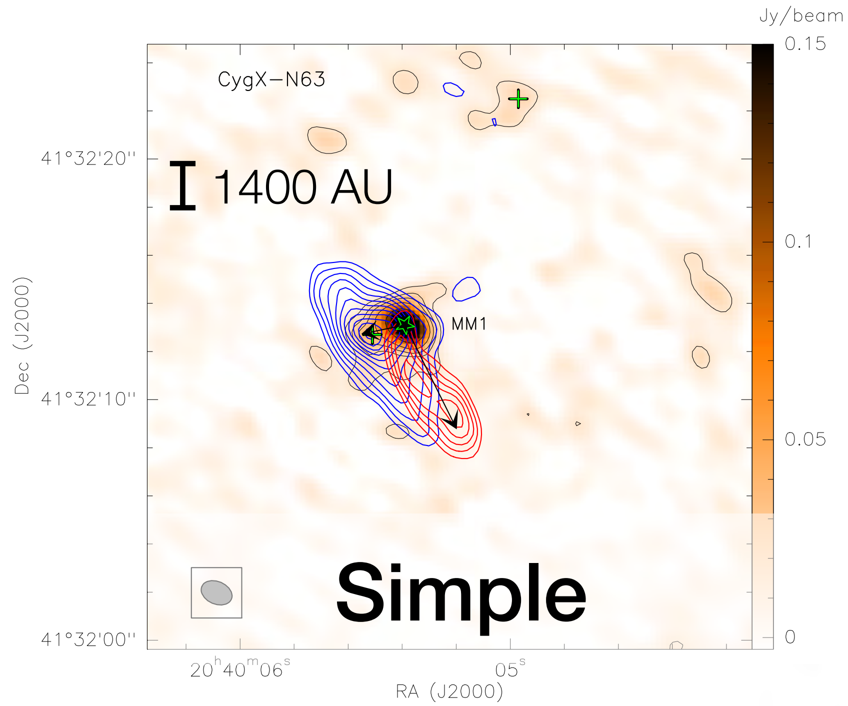
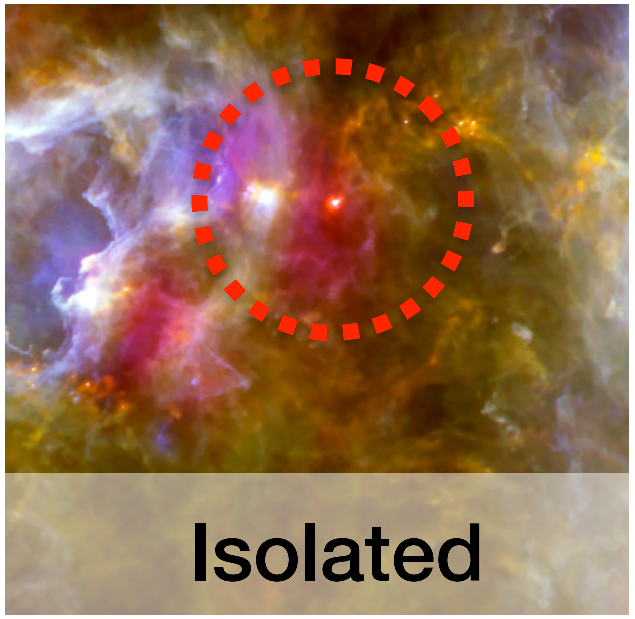
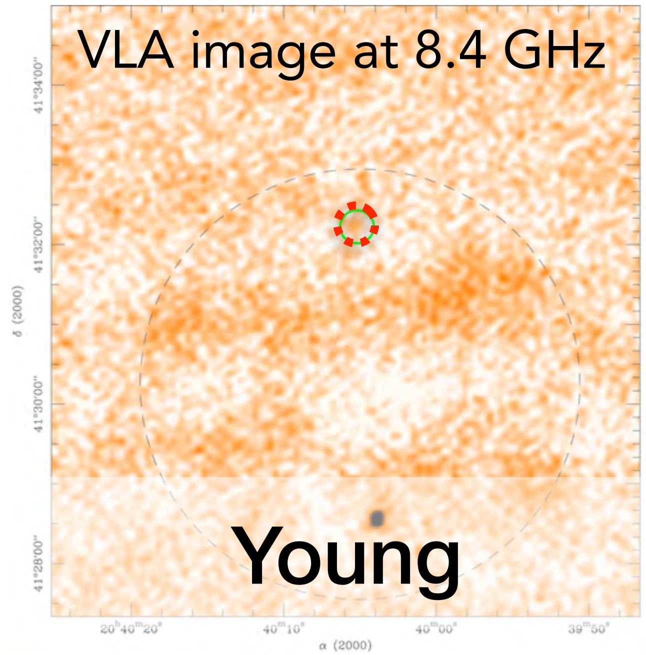


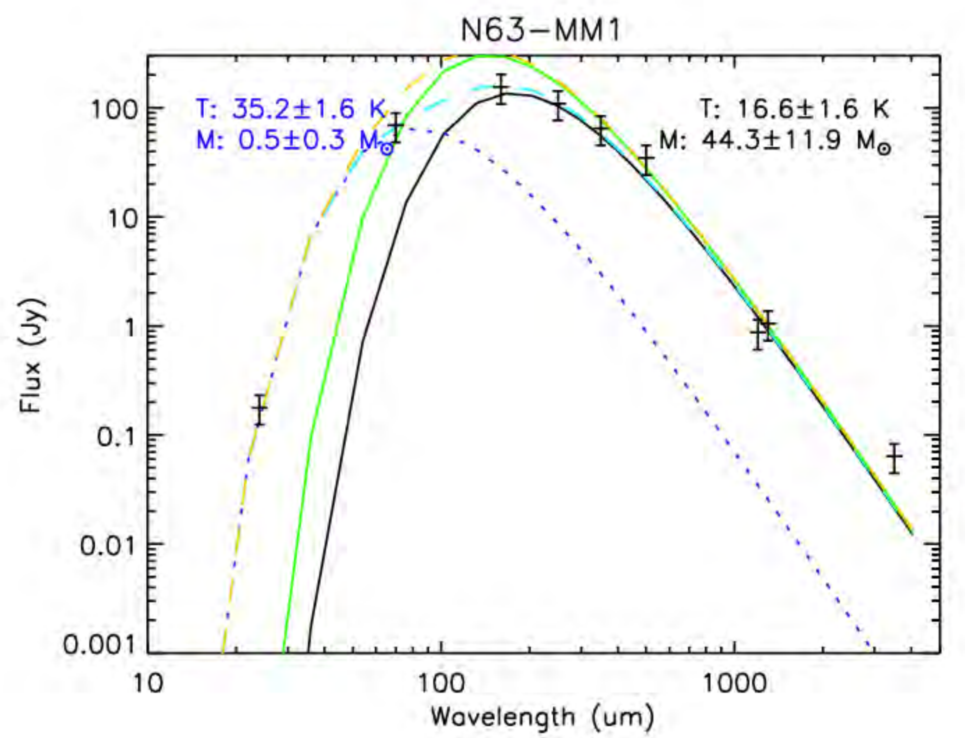




Massive

~44 M☉ in 2500 AU
350 L☉

Duarte-Cabral 2013



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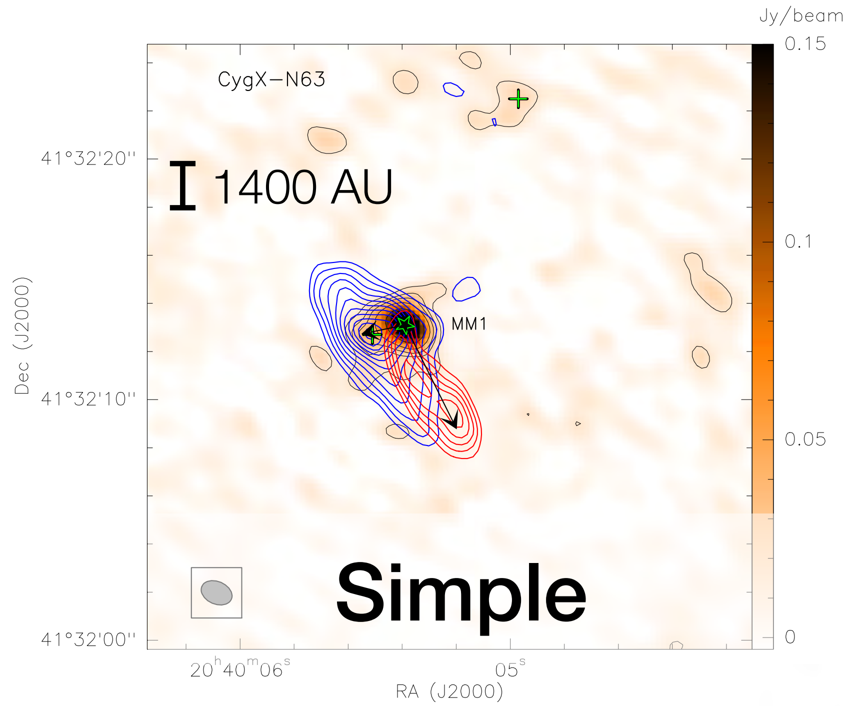

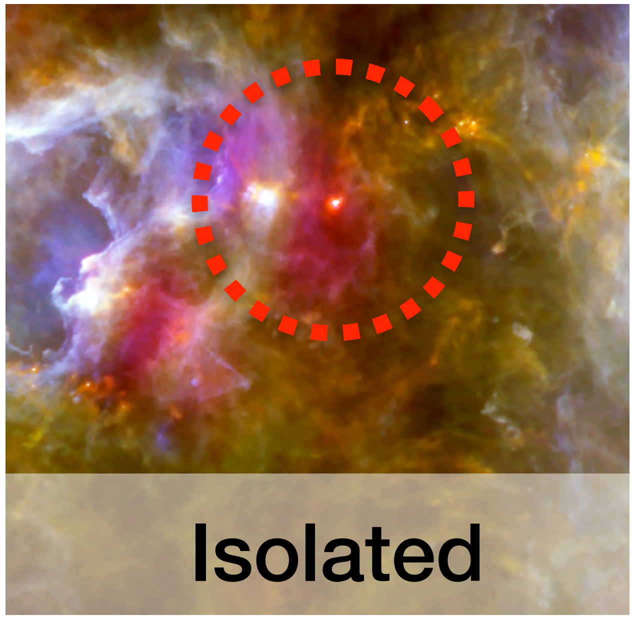

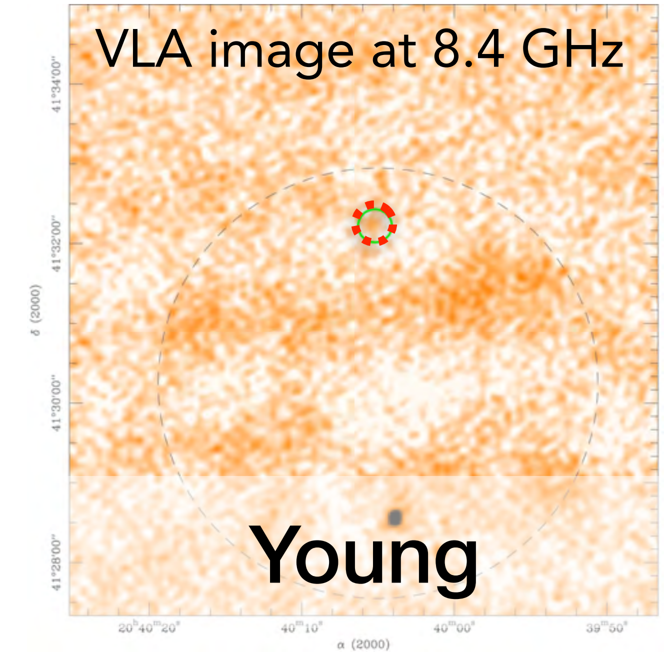

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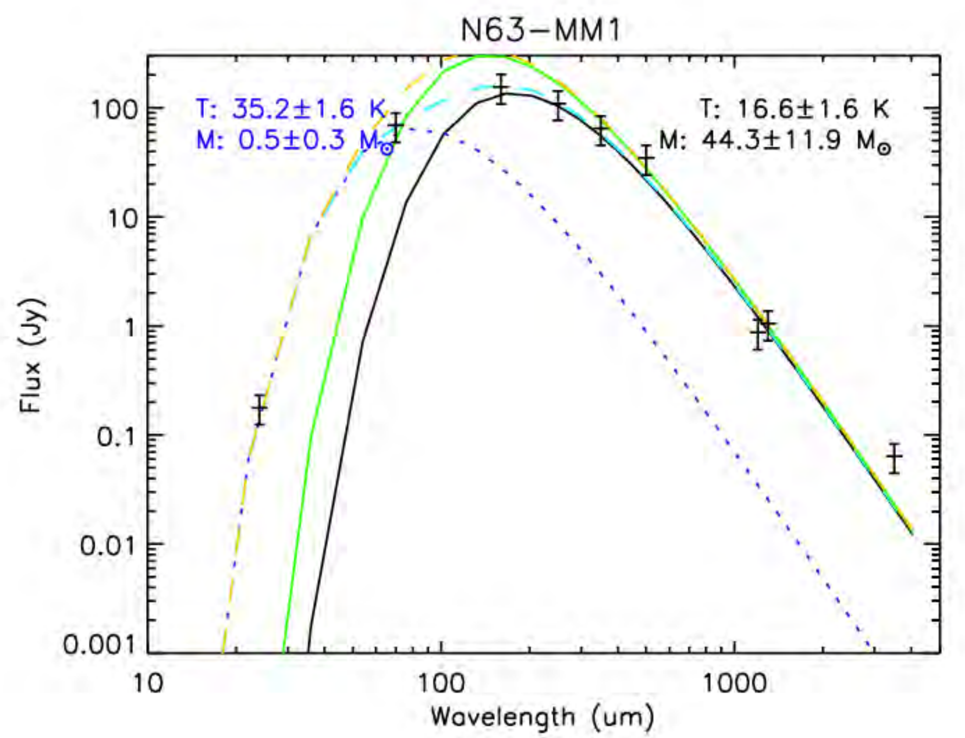


Future star of
20-25 M☉

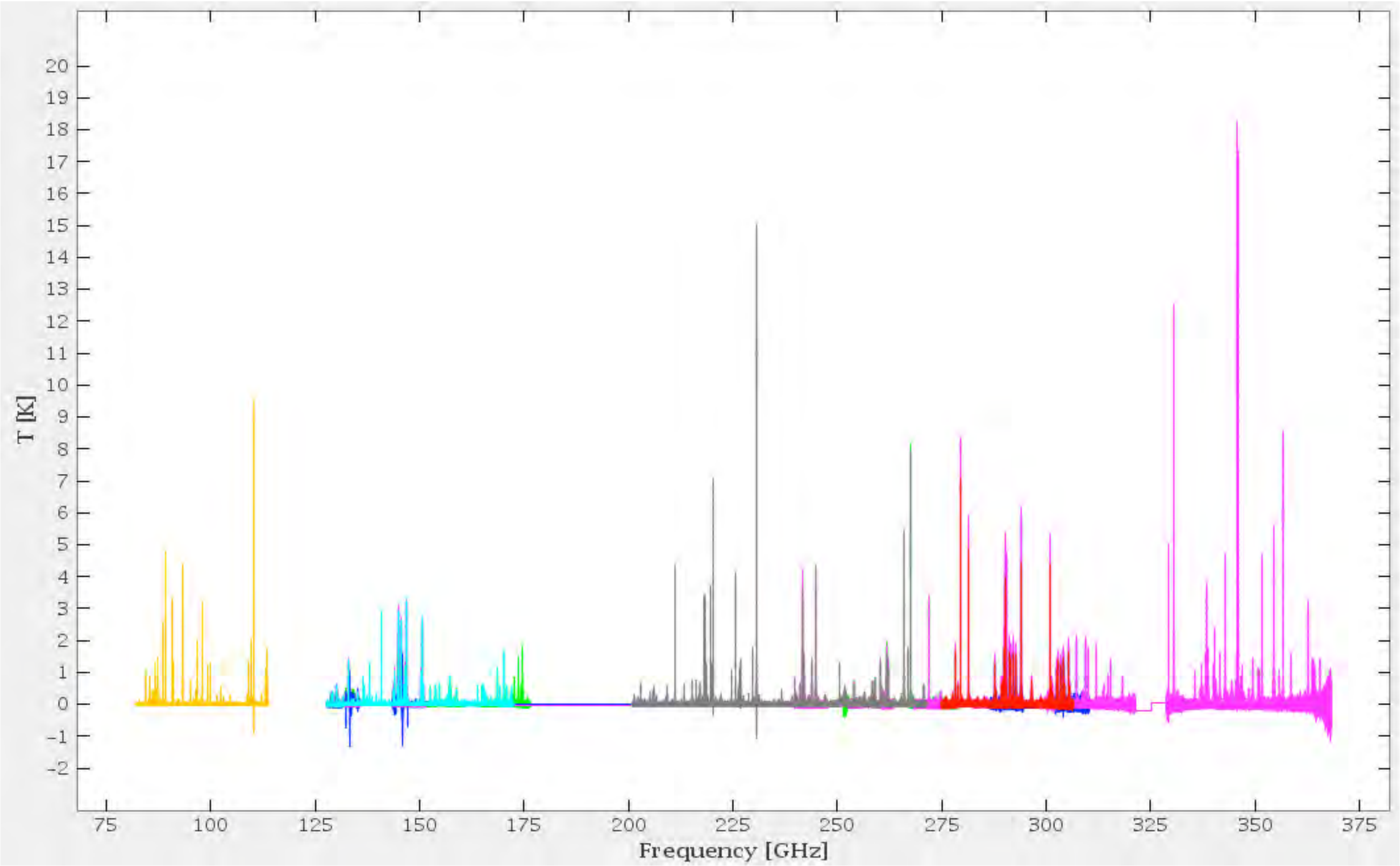
Unbiased spectral survey

My work !

235 hours of observation

181 GHz observed

~2600 lines at a 4 σ level



10 lines / GHz

rms ~ 3 mK 9 mK 19 mK

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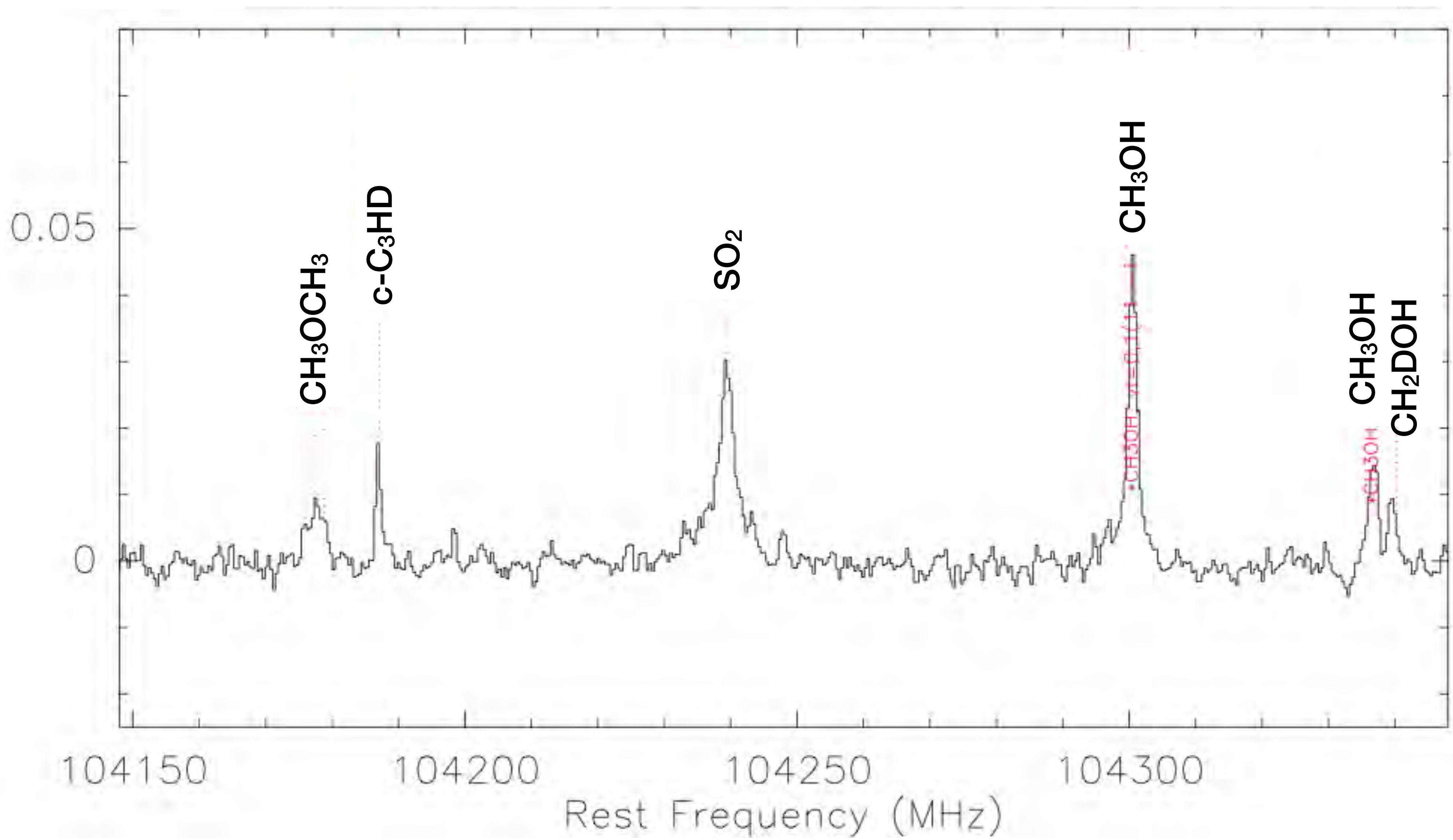

Chemical composition

- 95% of the lines identified
- 67 molecules
- Abundances determined for 56 molecules

CO
HCO
HCO^+
o/p-H_2CO
$HOCO^+$
H_2CCO
t-HCOOH
H_2COH^+ ?

CS
CCS
HCS^+
o/p-H_2S
H_2CS
SO
SO^+
SO_2
OCS
NS
CH_3SH ?

CN
N_2H^+
NO
HCN
HNC
HC_3N
HC_5N
HNCO
HONC
CH_3CN
C_2H_5CN
HCCNC
CH_2NH
NH_2CHO

N_2D^+
DCN
DNC
NH_2D
CH_2DOH
CH_3OD
HDO
DCO^+
$DOCO^+$?
HDCO
o/p-D_2CO
DC_3N
CCD
c-C_3HD
CH_2DCCH
HDCS

CH_3OH
CH_3CHO
CH_3OCH_3
CH_3OCHO
C_2H_5OH
CH_3COCH_3
Ethylene oxide

CCH
c-C_3H
C_4H
o/p-c-C_3H_2
a/e-CH_3CCH

SiO
CF^+
PN ?

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H_2COH^+ ?

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HCS^+
o/p-H_2S
H_2CS
SO
SO^+
SO_2
OCS
NS
CH_3SH ?

CN
N_2H^+
NO
HCN
HNC
HC_3N
HC_5N
$HNCO$
$HONC$
CH_3CN
C_2H_5CN
$HCCNC$
CH_2NH
NH_2CHO

N_2D^+
DCN
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NH_2D
CH_2DOH
CH_3OD
HDO
DCO^+
$DOCO^+$?
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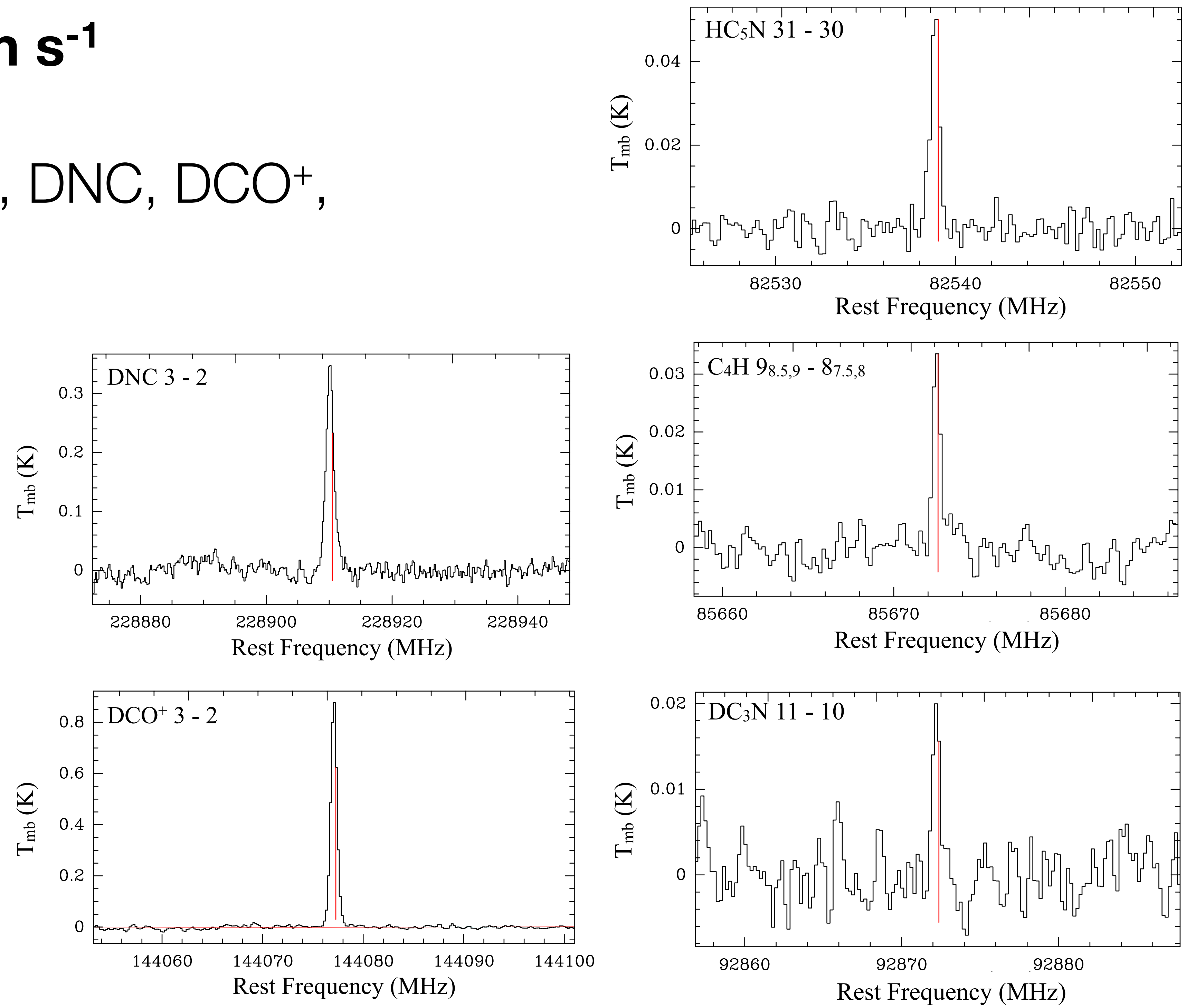
Spatial analysis: spectral profiles

Narrow lines < 2 km s^{-1}

Including N_2H^+, N_2D^+, DNC, DCO^+, NH_2D, C_3H, C_4H…

T_{ex} = 13 K



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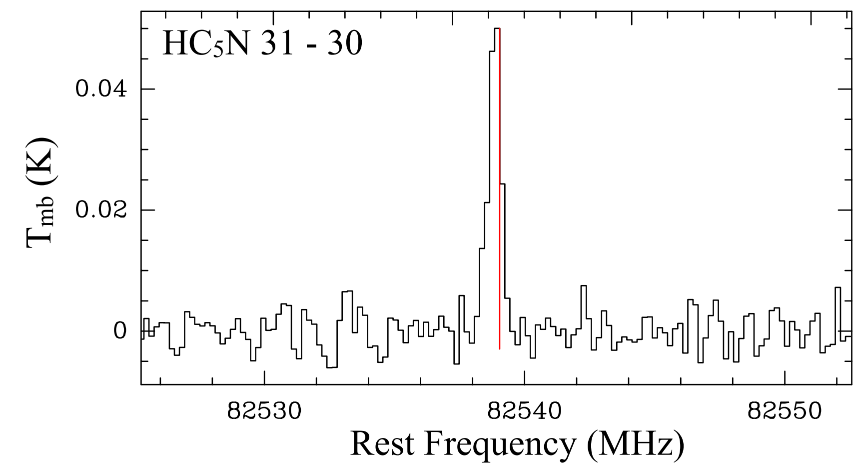
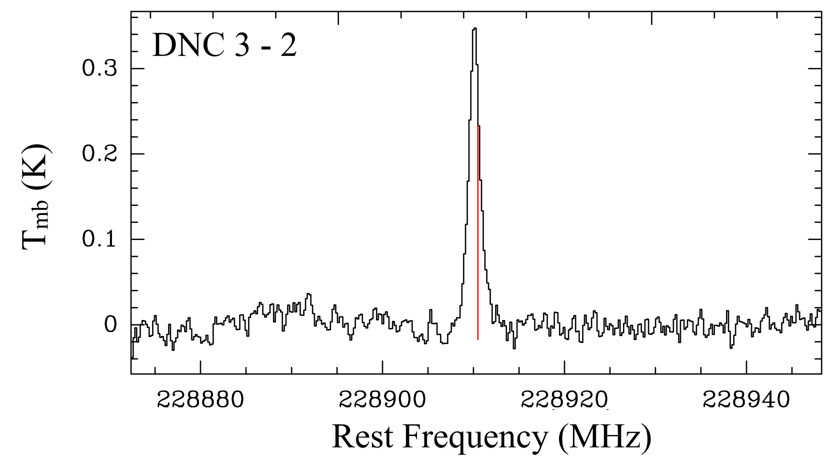
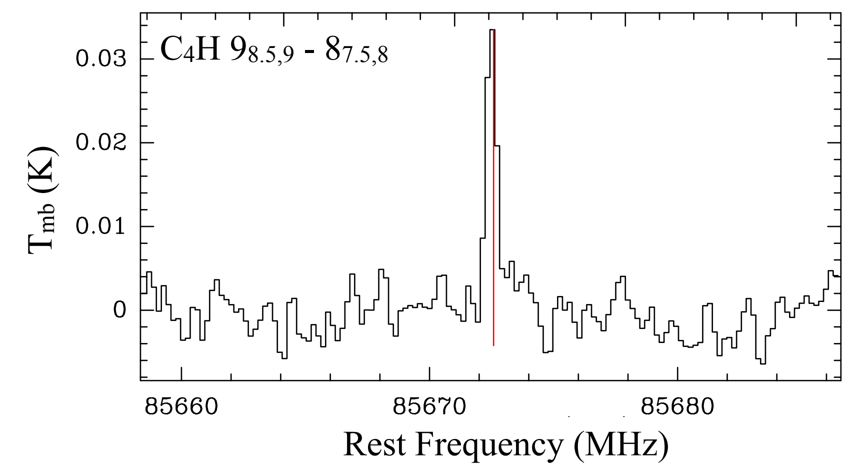
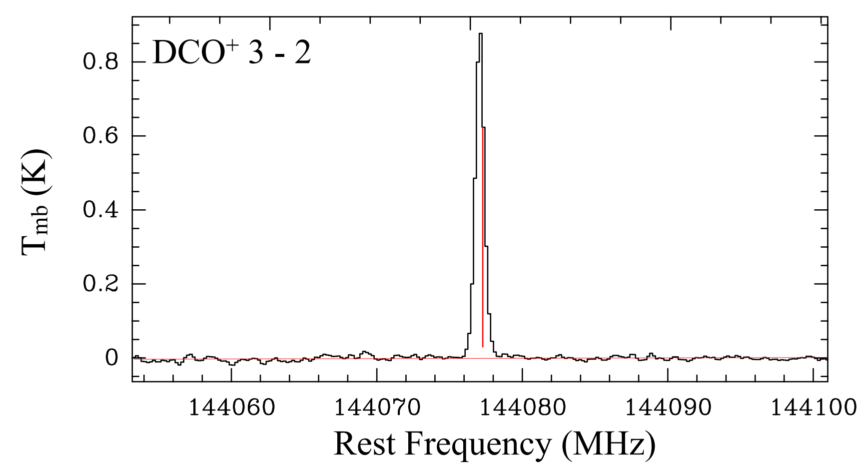
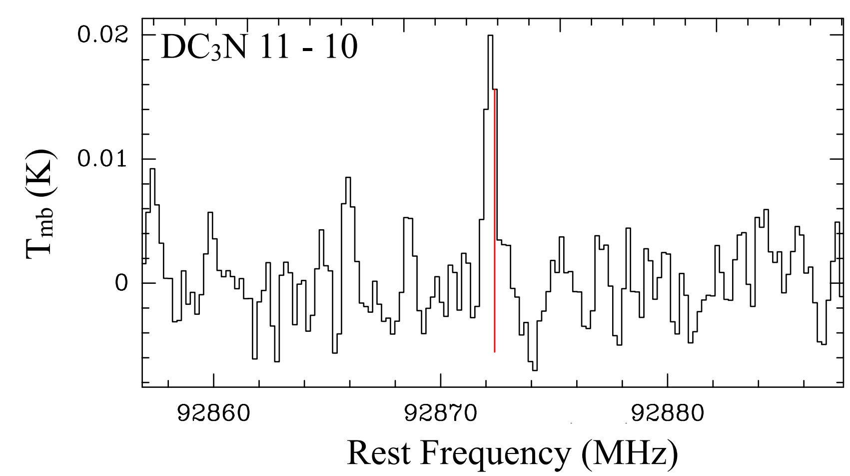
Envelope tracers









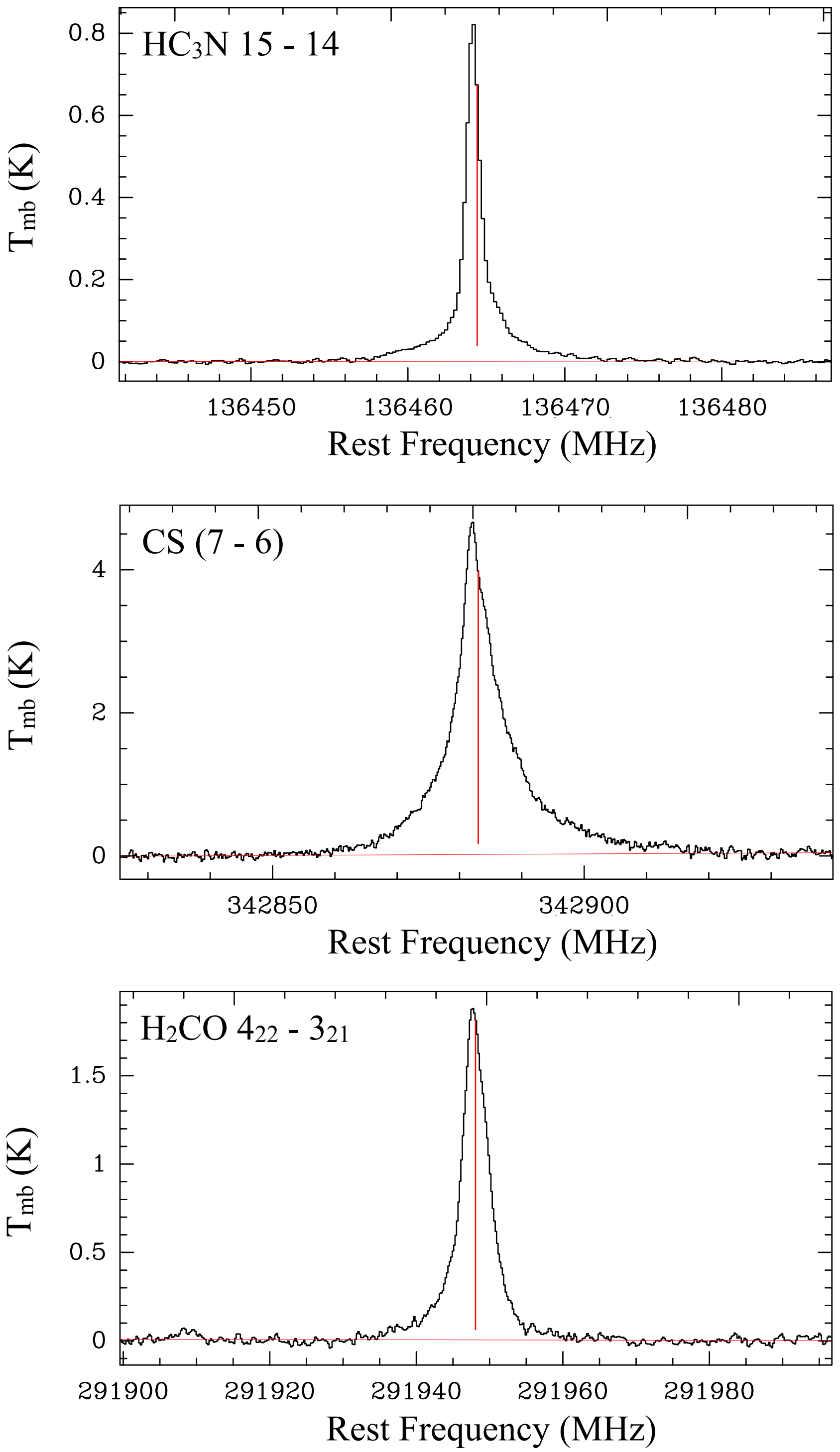


Spatial analysis: spectral profiles

Broad lines

A large part of the molecules, including H_2CO, HCN, CS, CN

T_{ex} = 14 and 17 K



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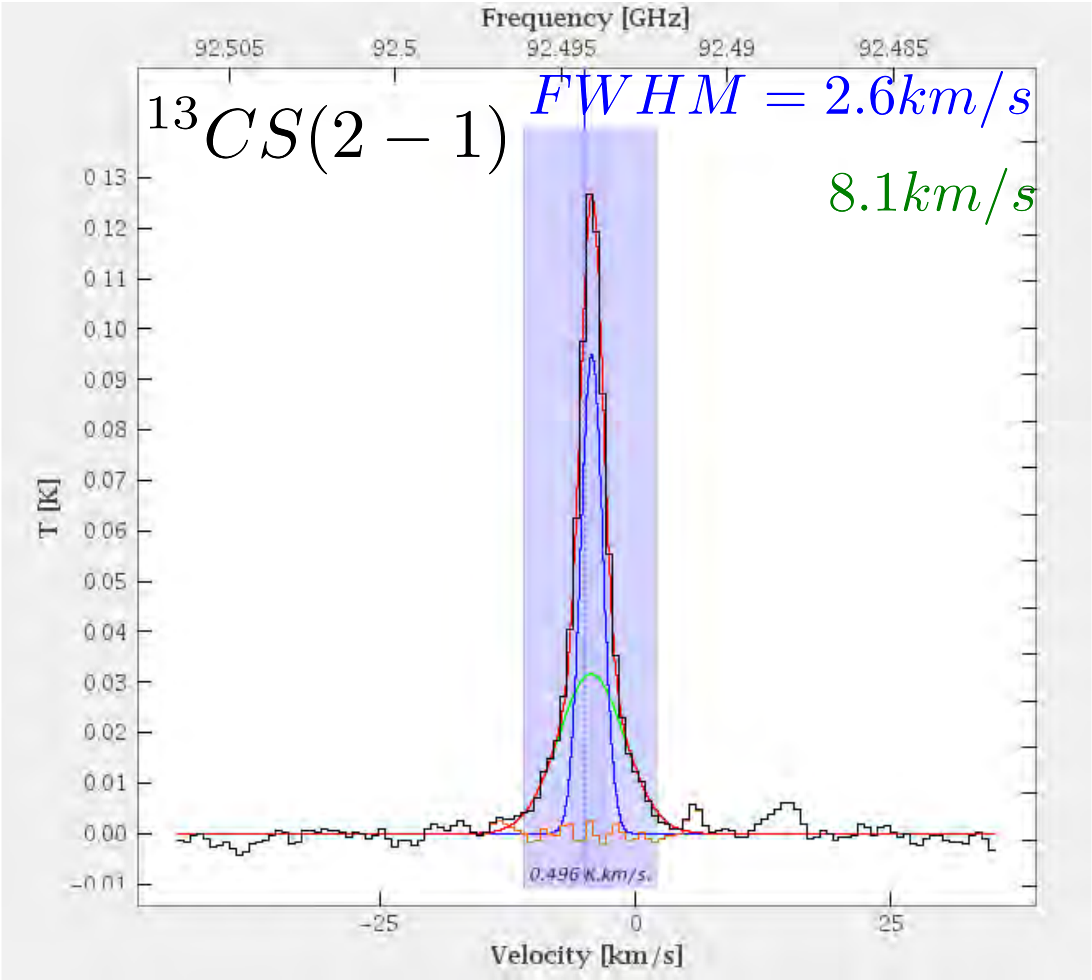

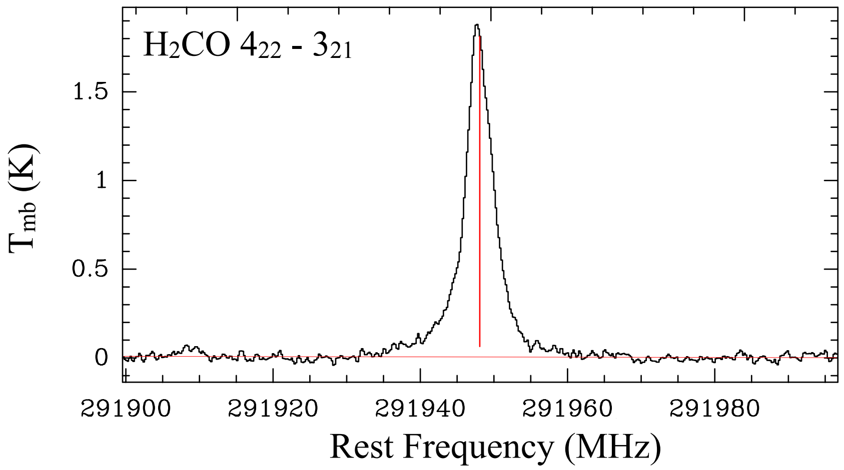

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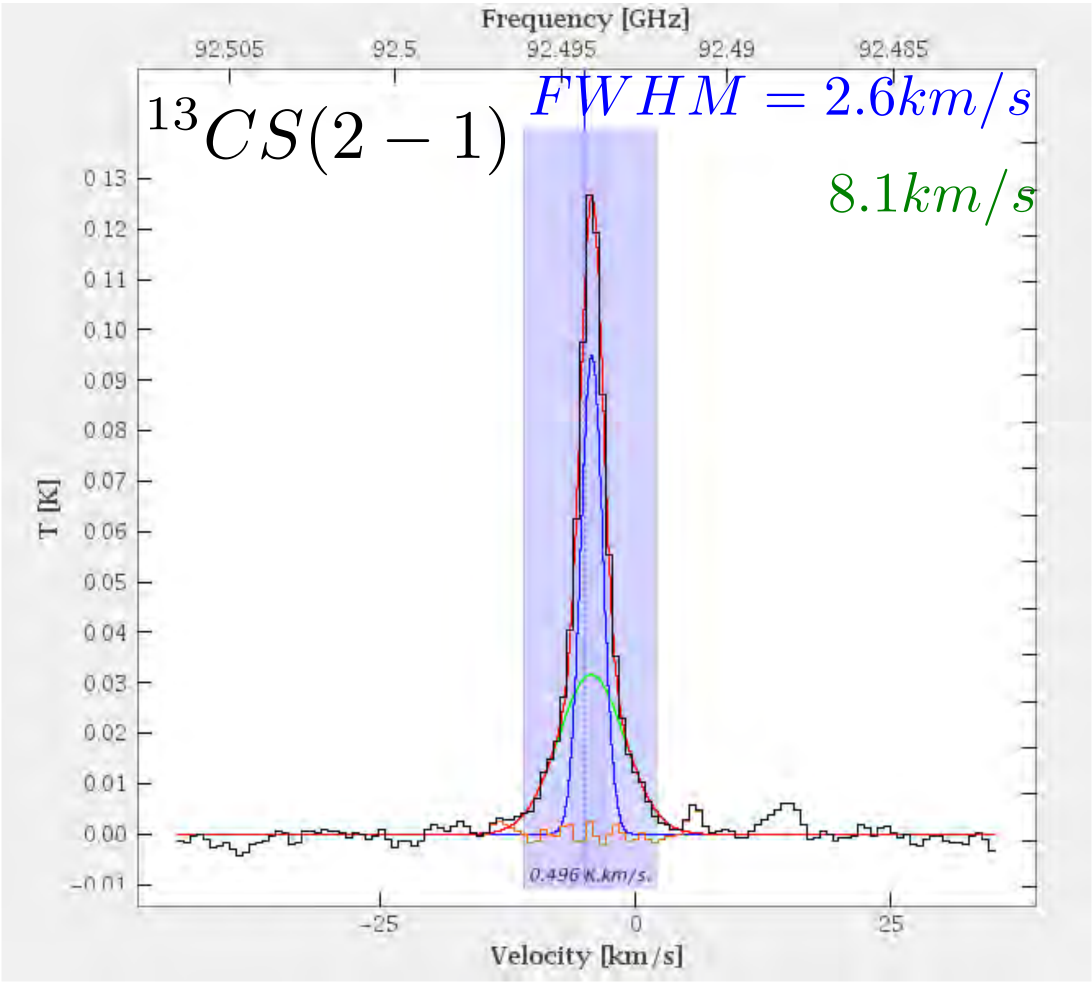

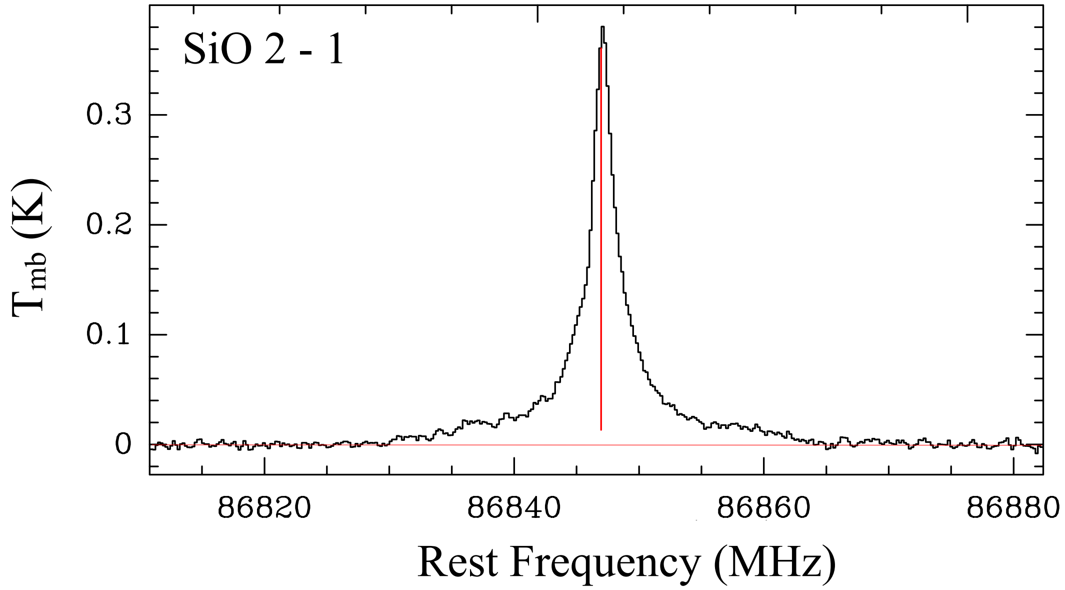

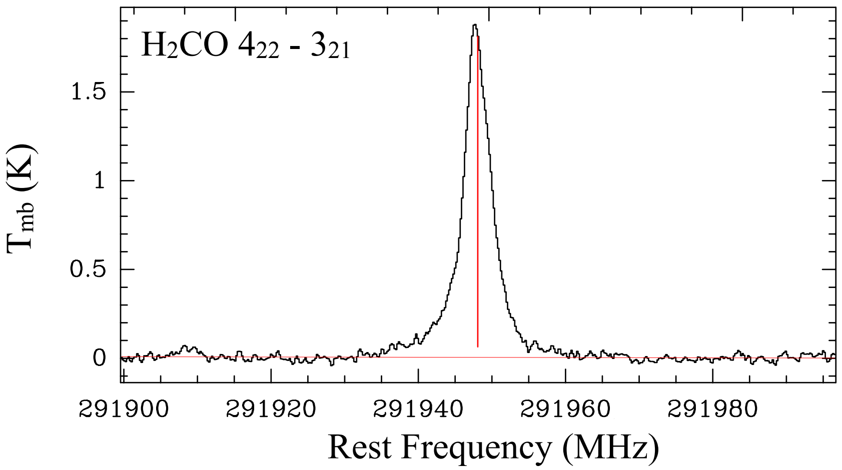

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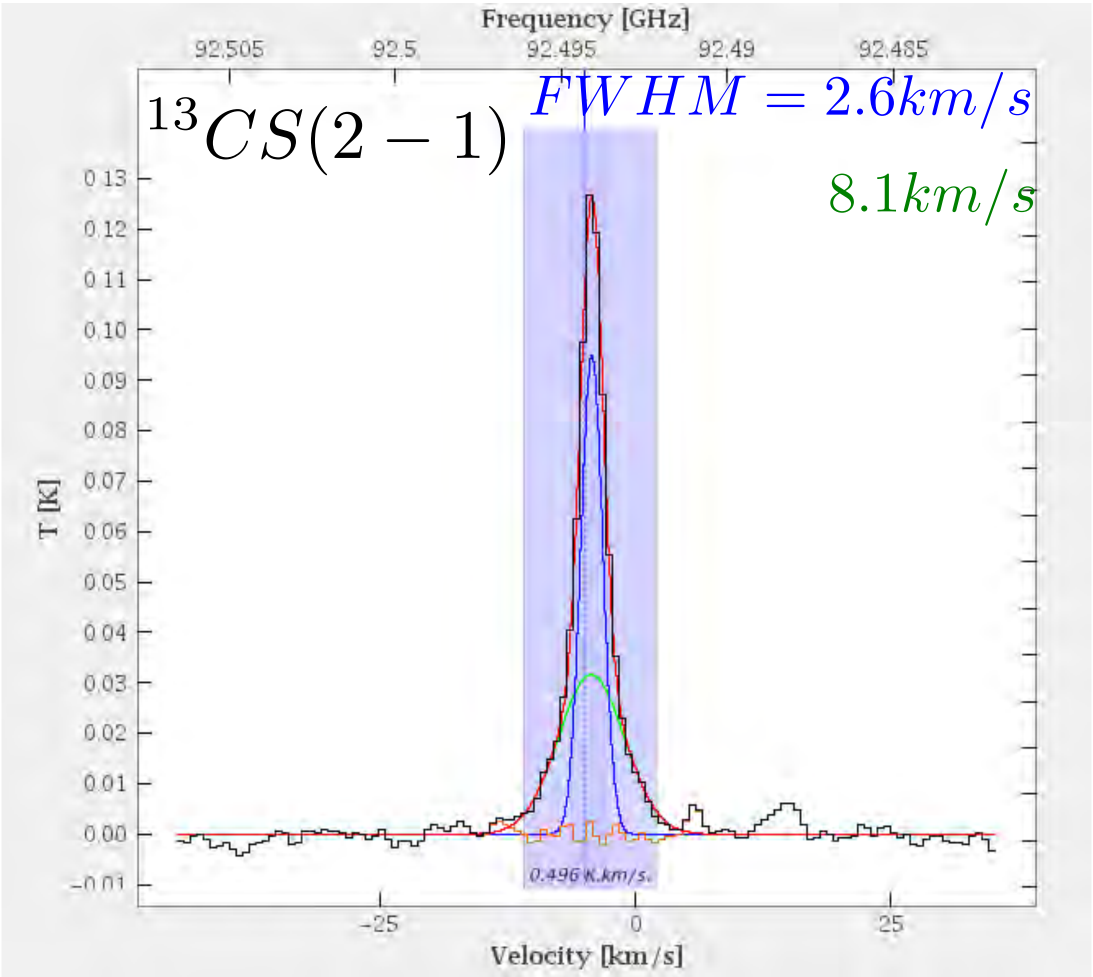
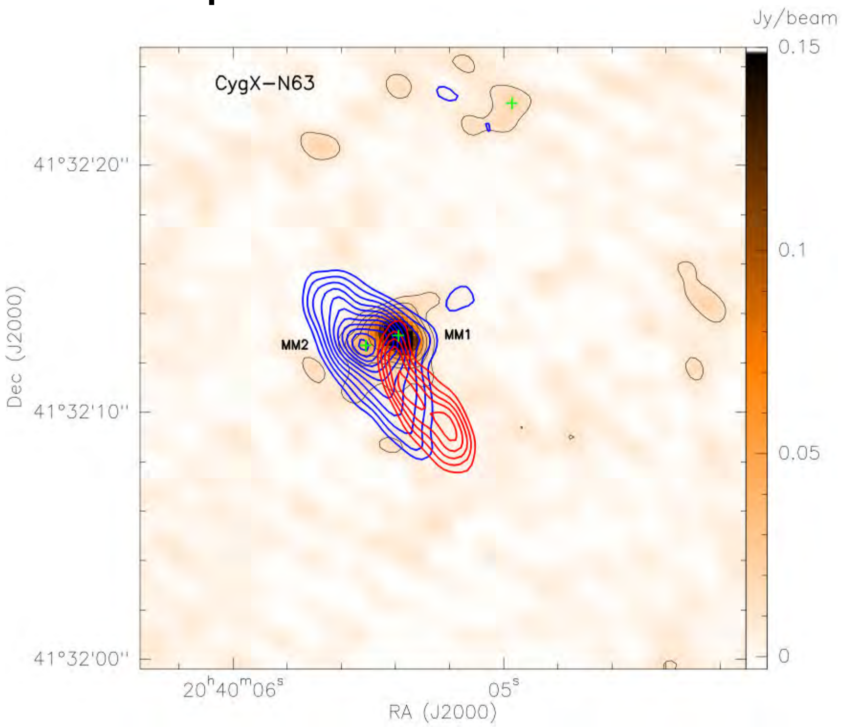
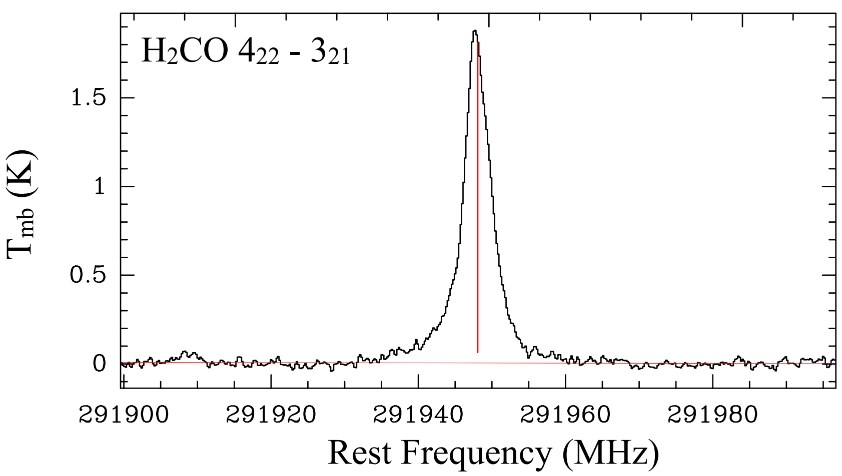




Probably influenced by the outflow

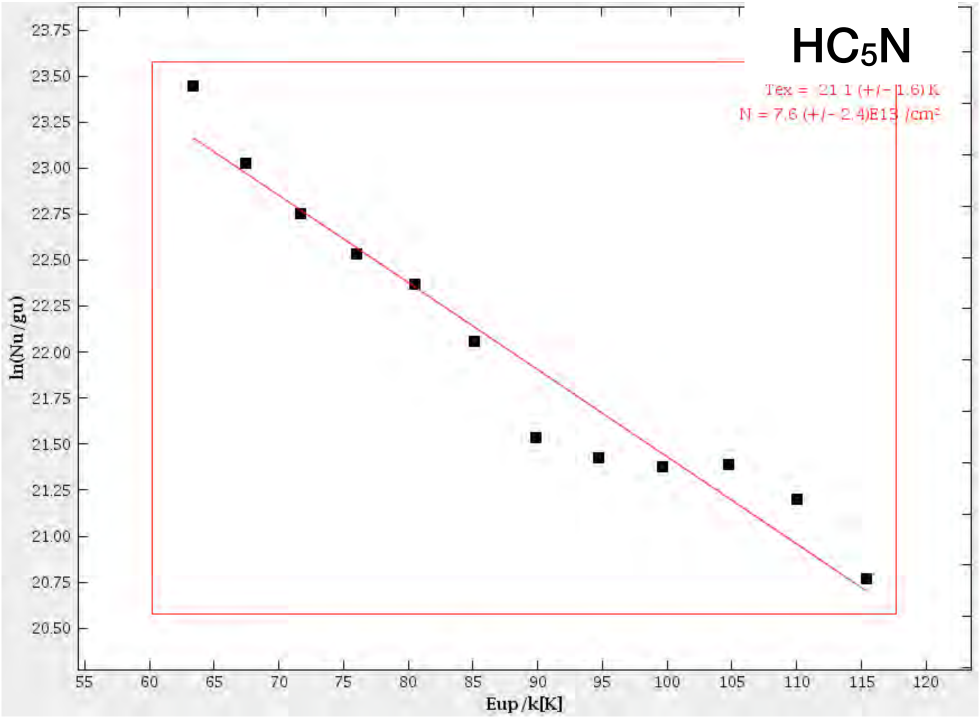


Spatial analysis: population diagrams

Most of the population diagrams show a unique slope.

All oxygen-bearing COMs have two slopes: CH_3OH, CH_3CHO, CH_3OCH_3, CH_3OCHO, C_2H_5OH + CH_3CN

=> low T_{ex} ~ 21 K and high T_{ex} ~130 K



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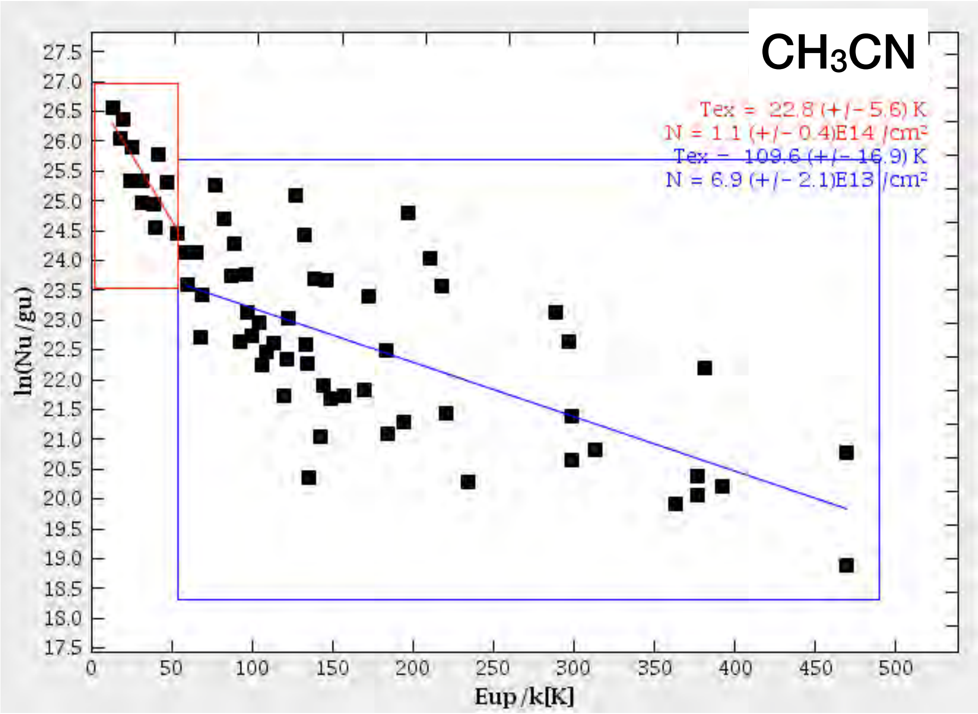

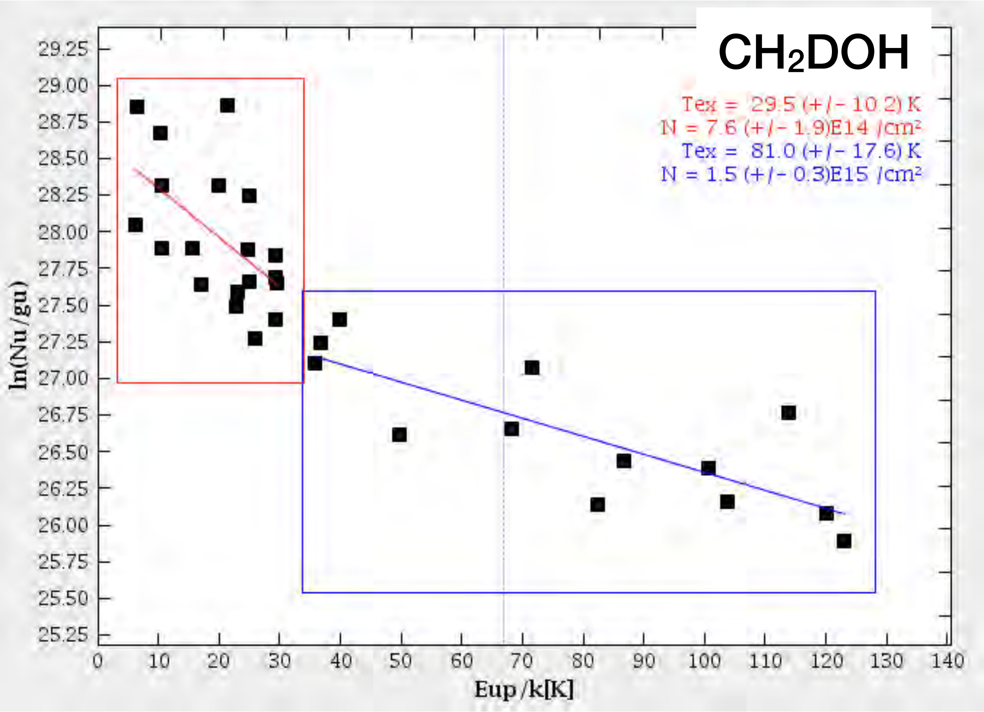

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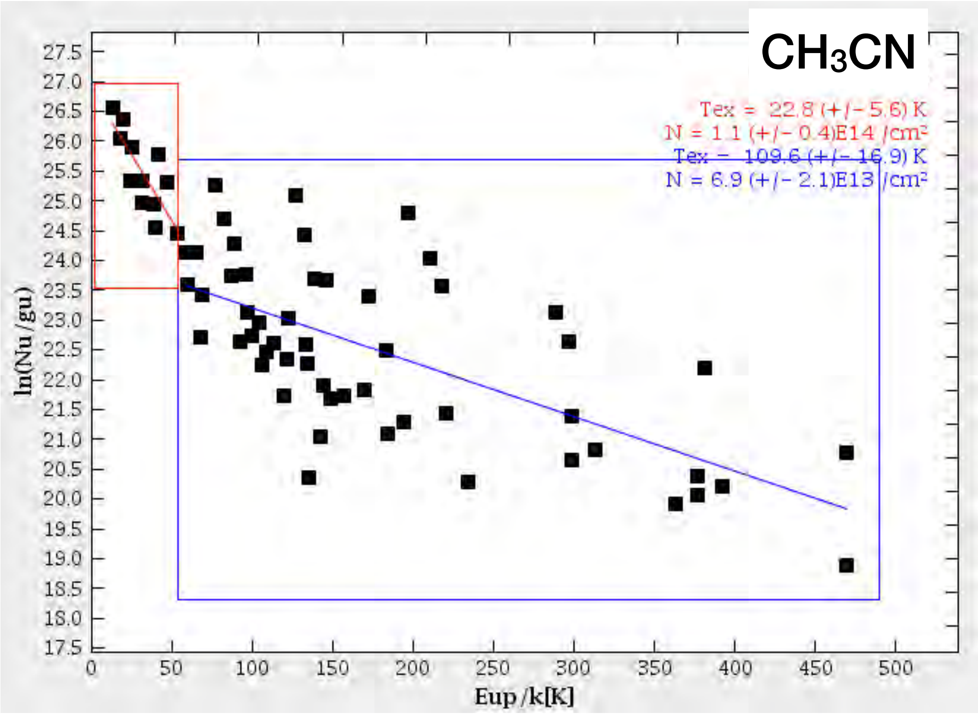
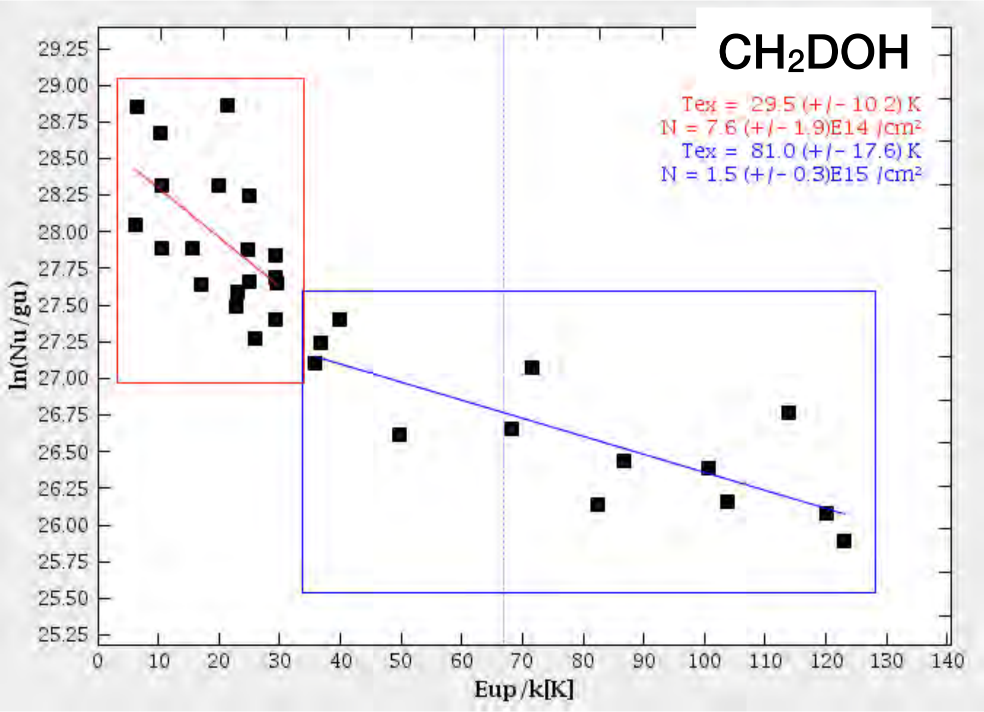
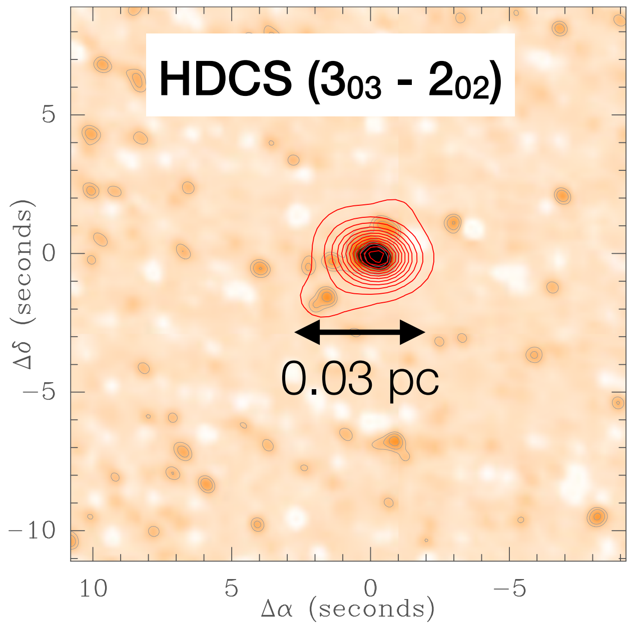
Hot core tracers

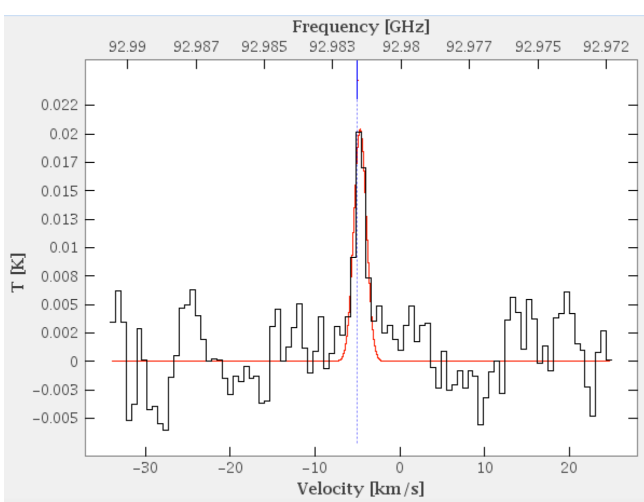




Spatial analysis: PdBI observations

29 transitions observed with the PdBI





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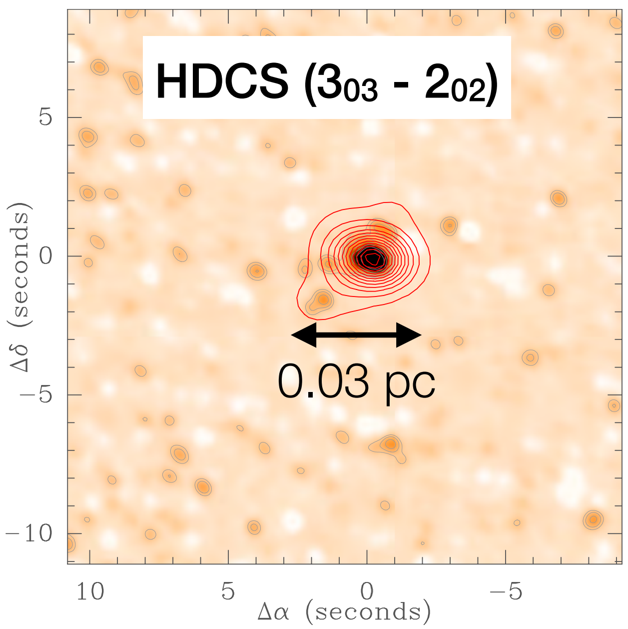

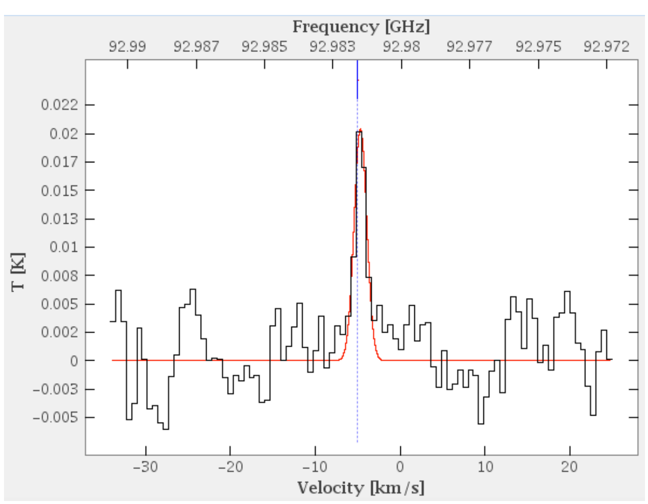

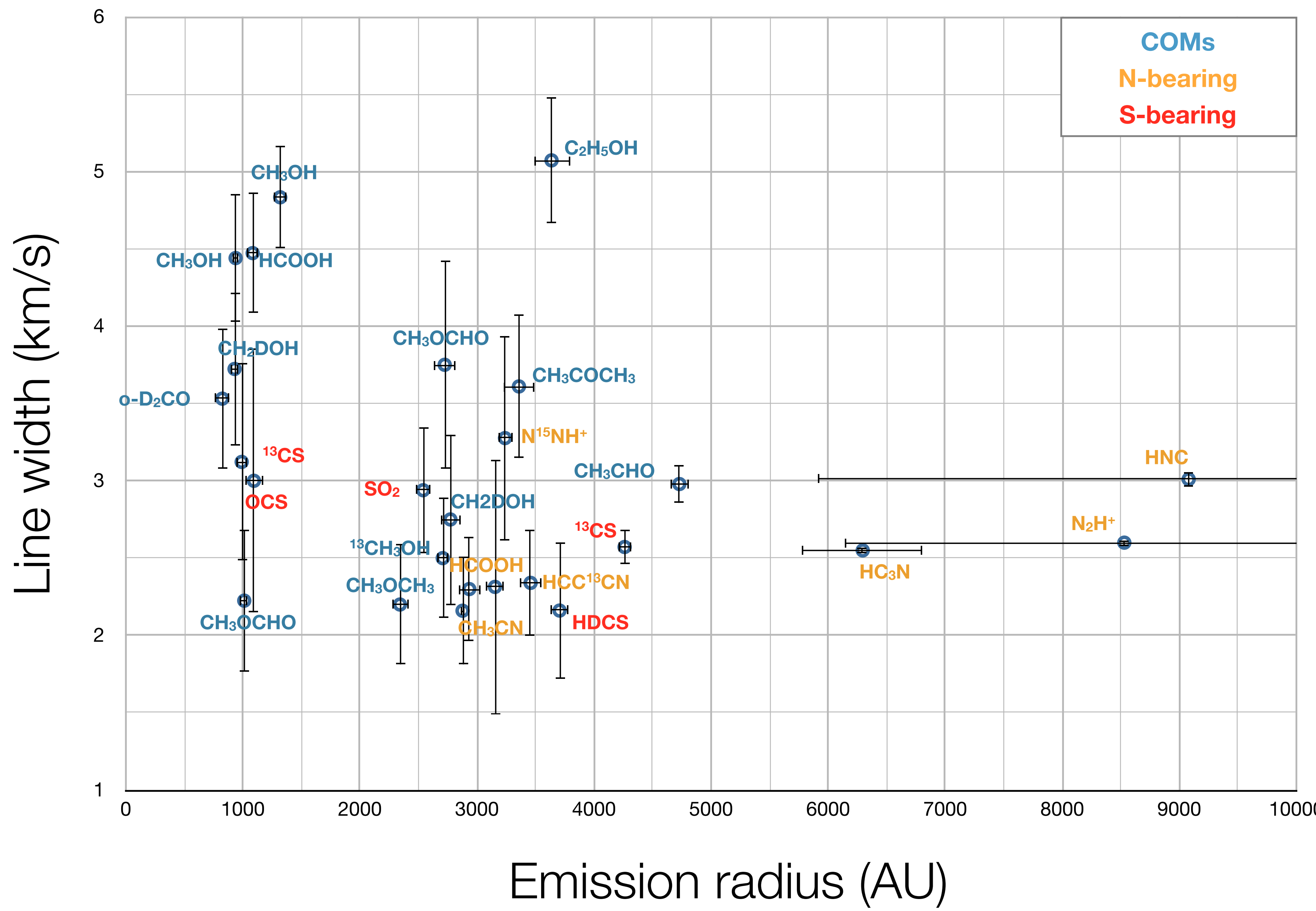

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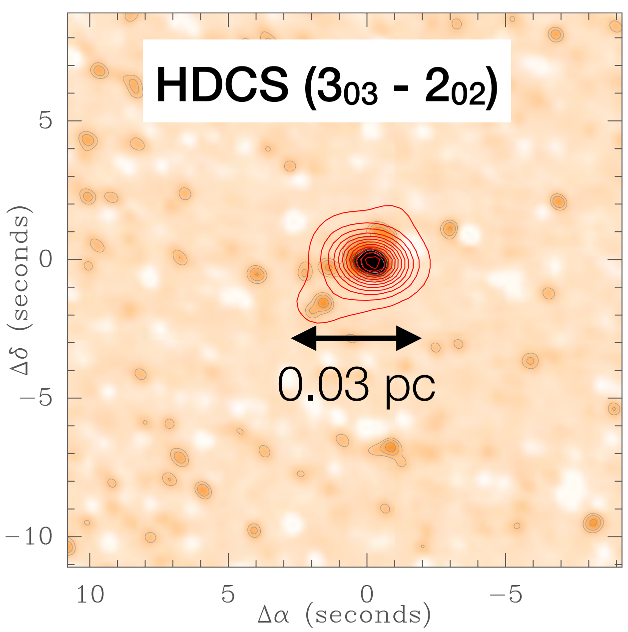

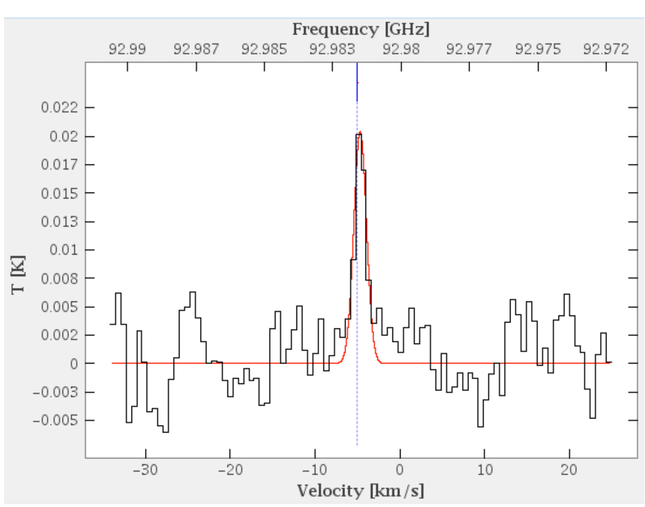

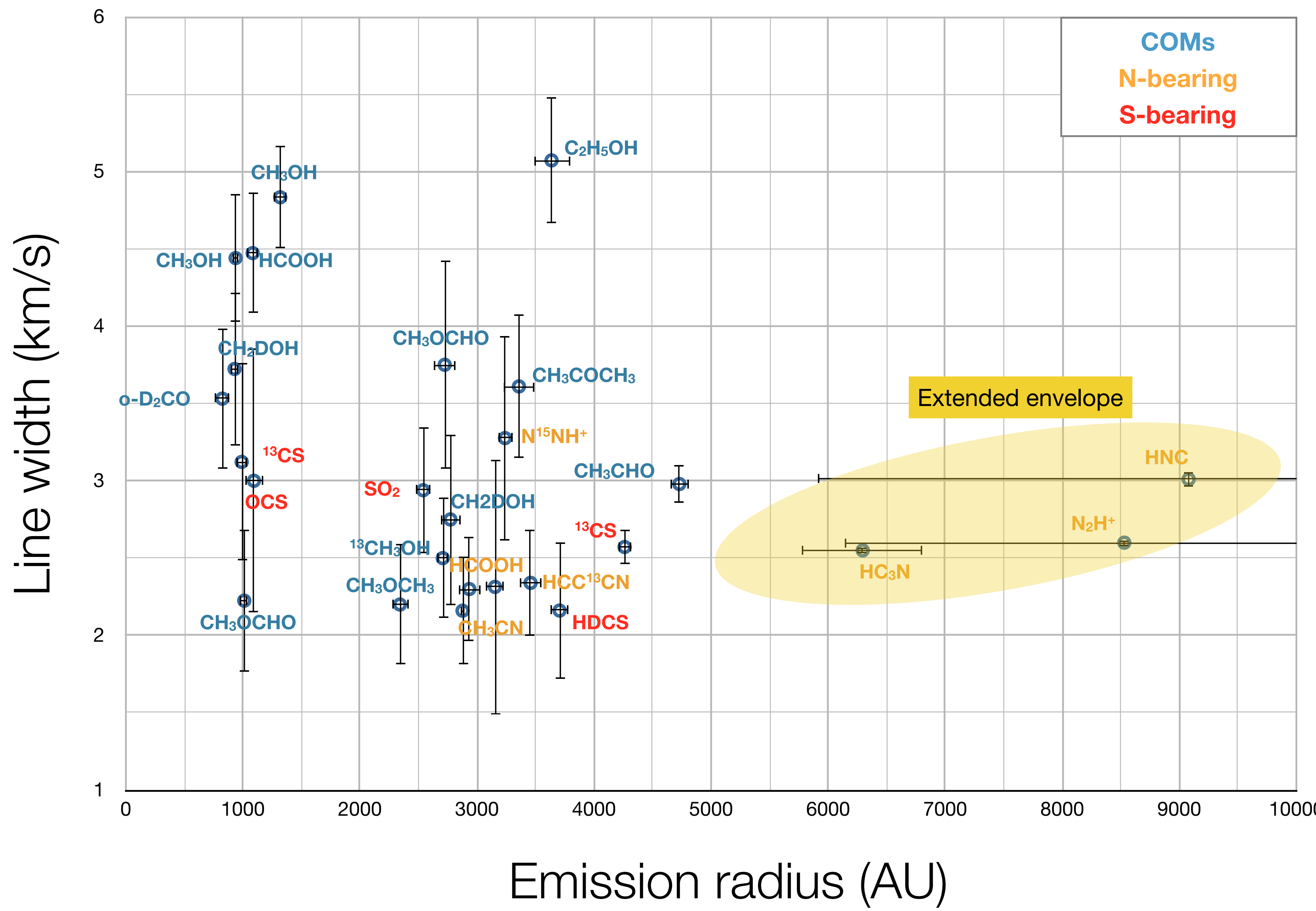

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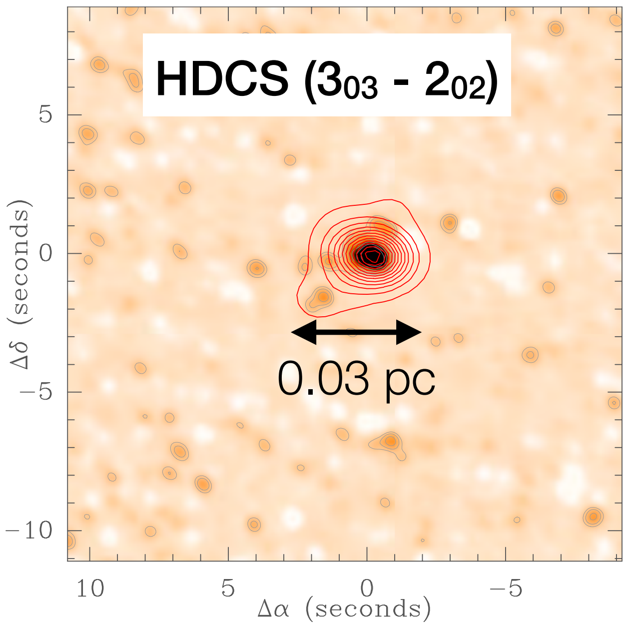

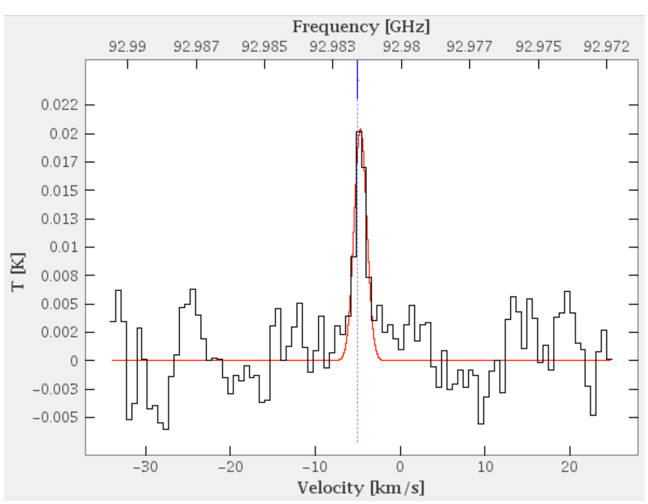

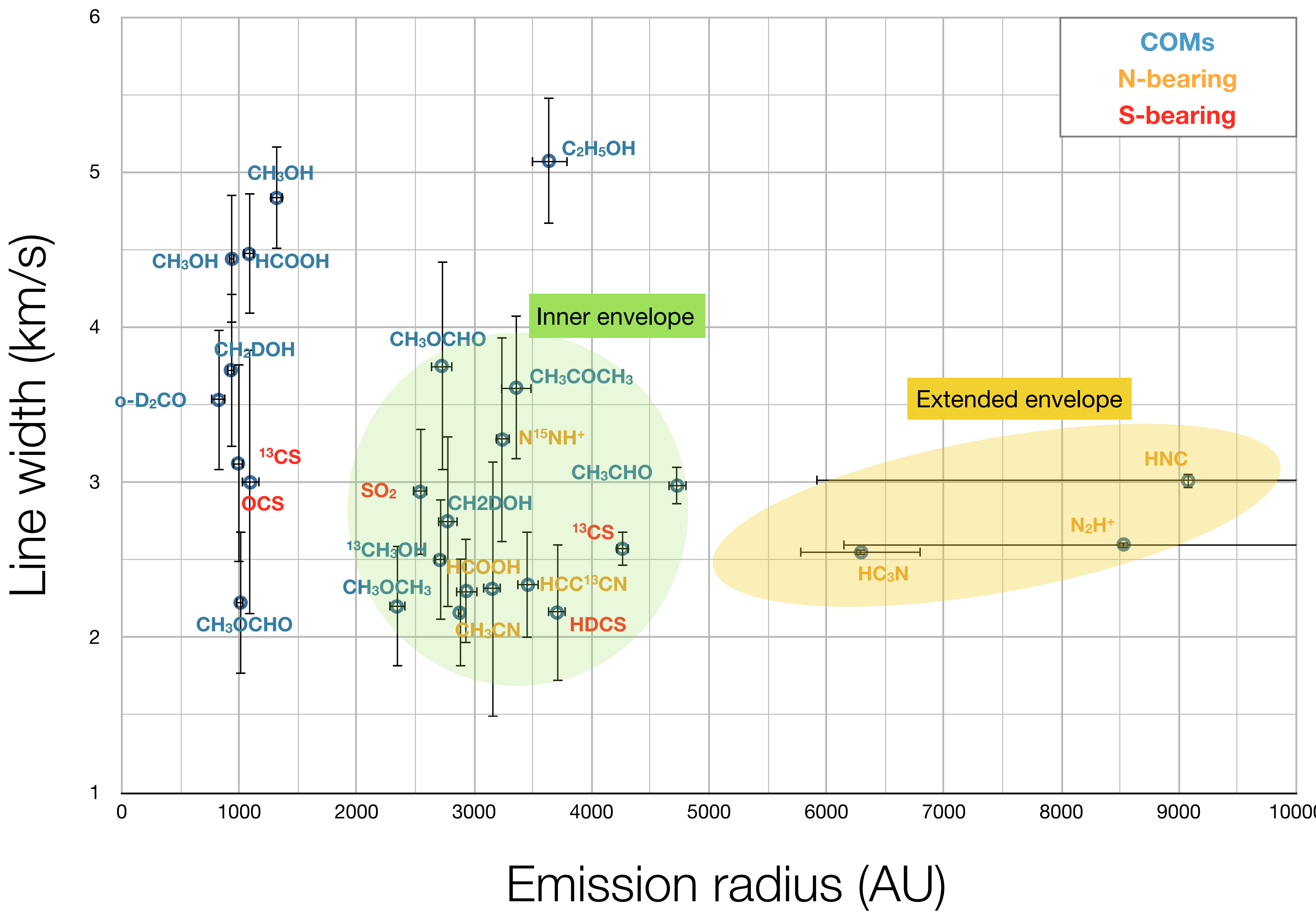

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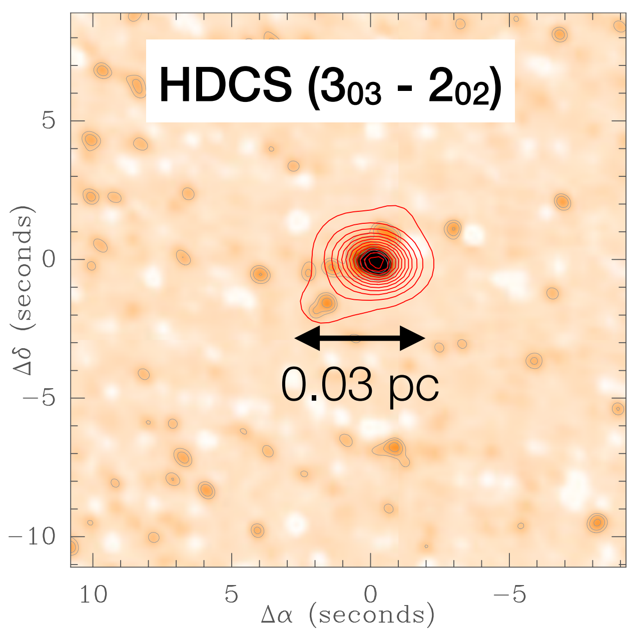
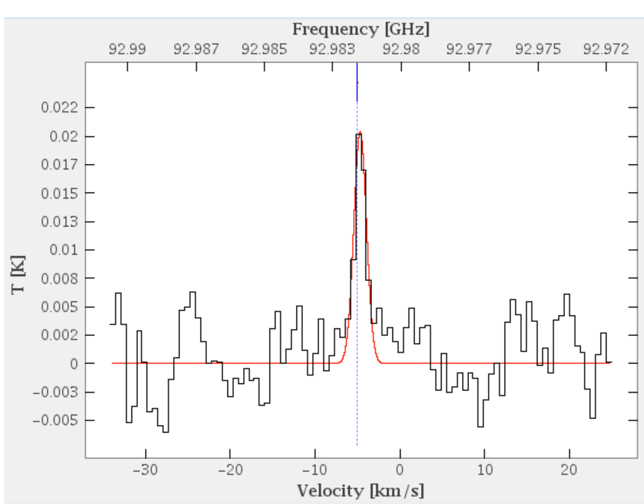
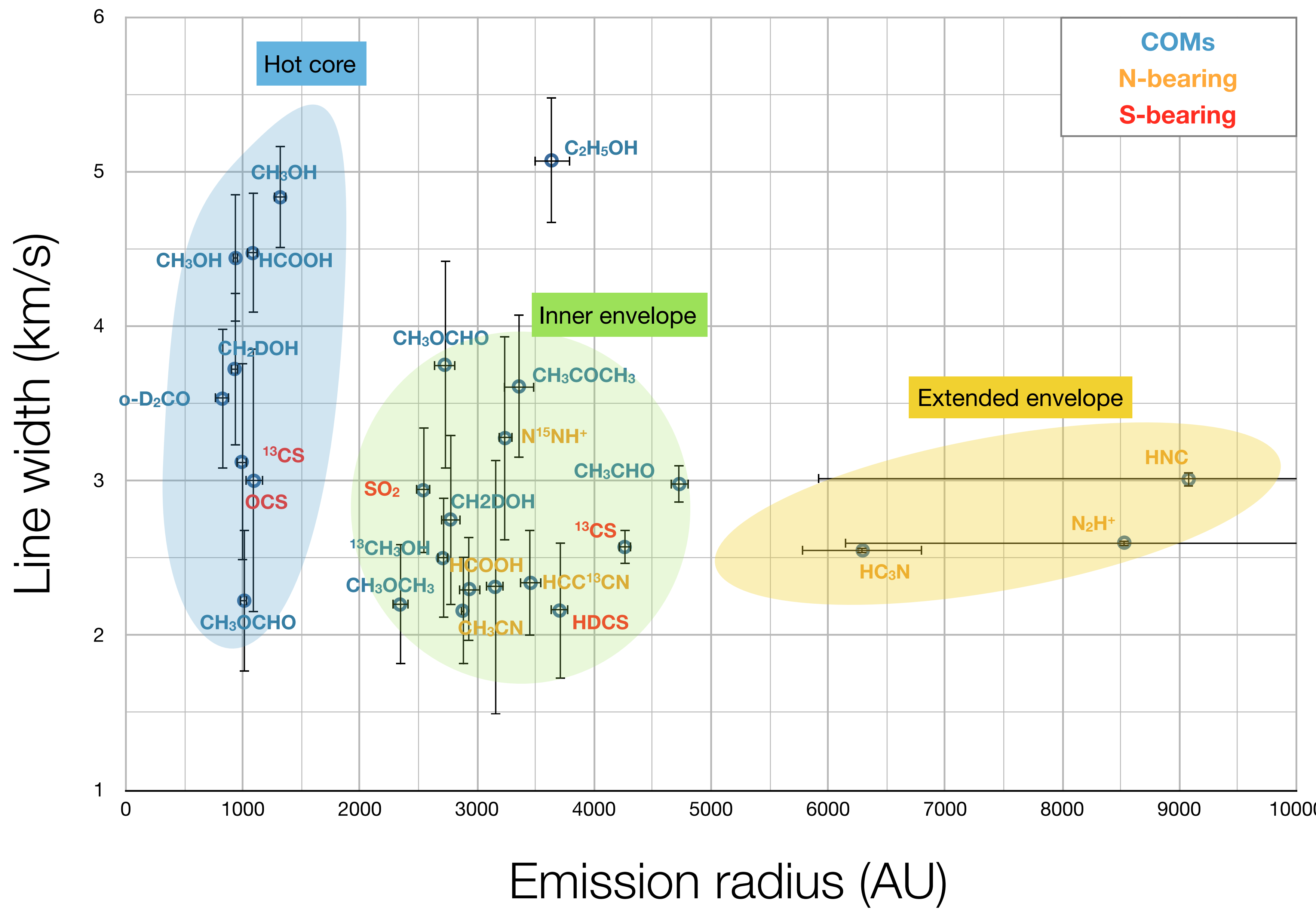
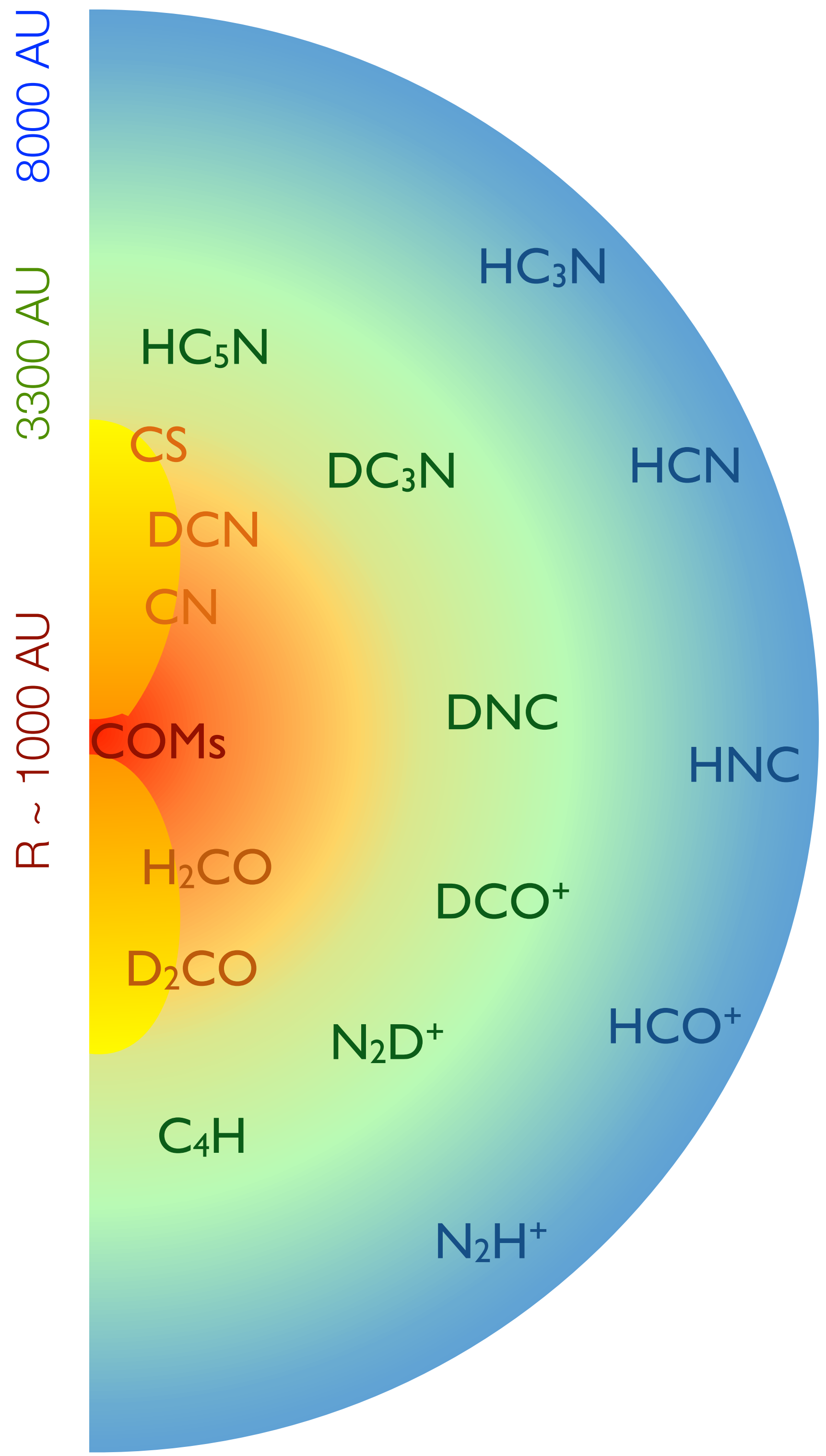






Spatial analysis - summary



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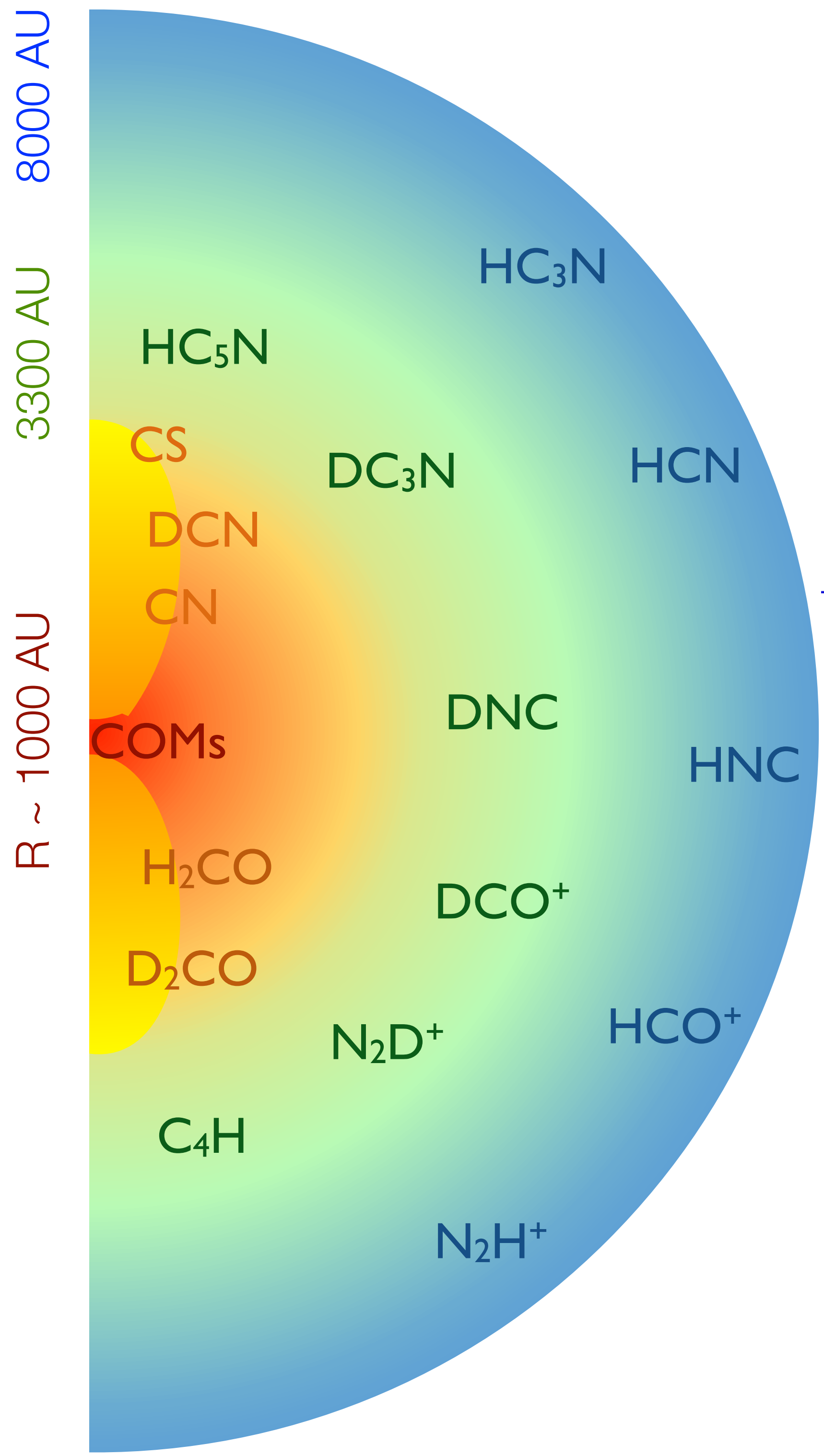
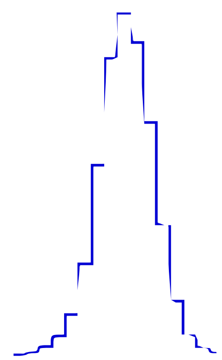


Extended envelope

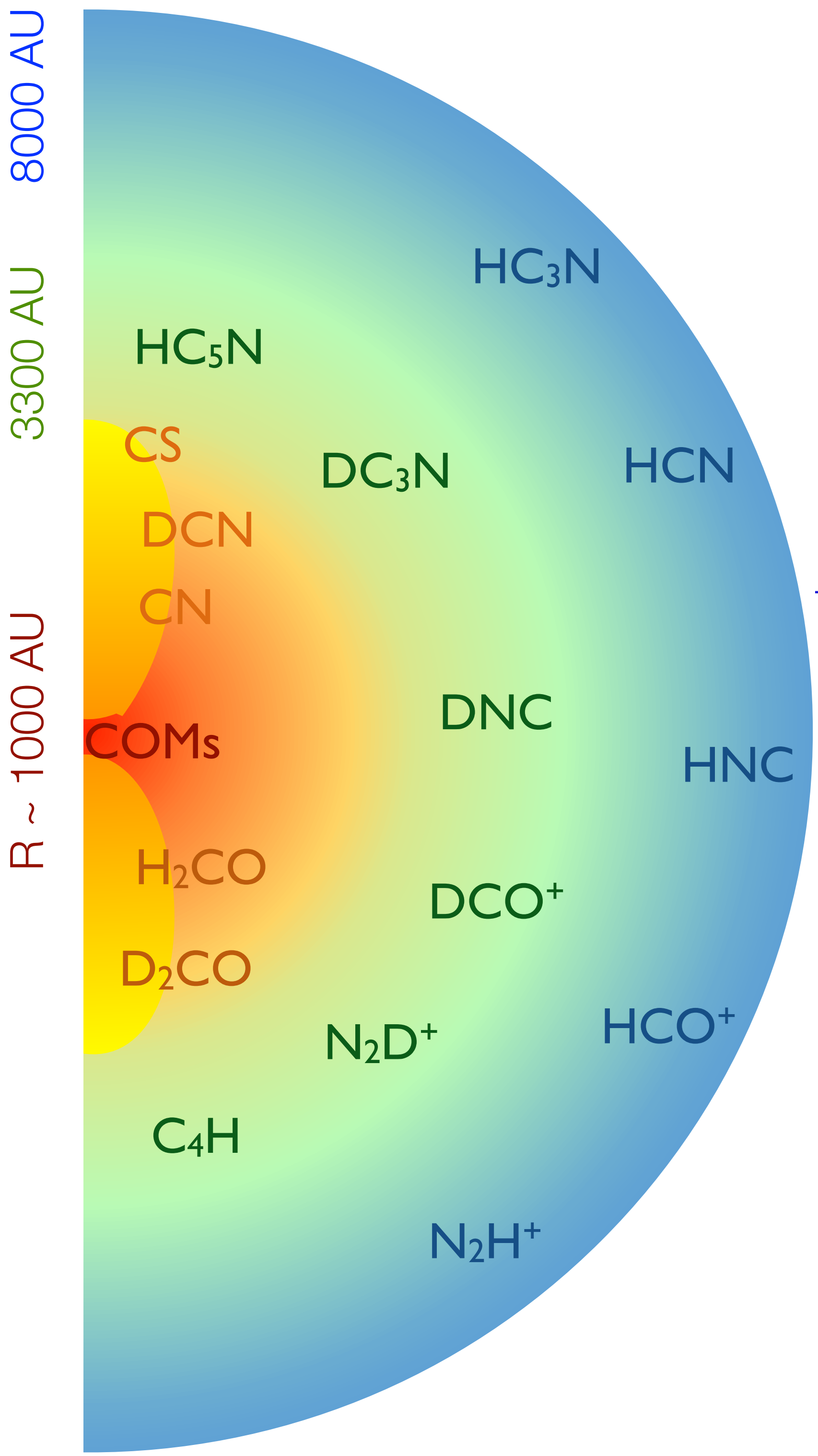


HNC

$$\langle \mathrm{FWHM_n} \rangle = (2.9 \pm 0.)\mathrm{km\ s^{-1}}$$

$$\langle \mathrm{FWHM_b} \rangle = (6.9 \pm 0.4)\mathrm{km\ s^{-1}}$$

Spatial analysis - summary



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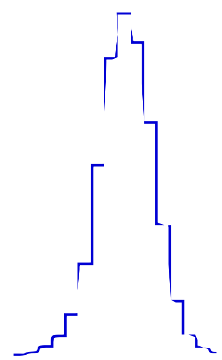
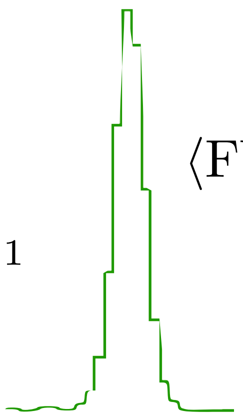


HNC

$$\langle \mathrm{FWHM_n} \rangle = (2.9 \pm 0.)\mathrm{km\ s^{-1}}$$

$$\langle \mathrm{FWHM_b} \rangle = (6.9 \pm 0.4)\mathrm{km\ s^{-1}}$$

Inner envelope

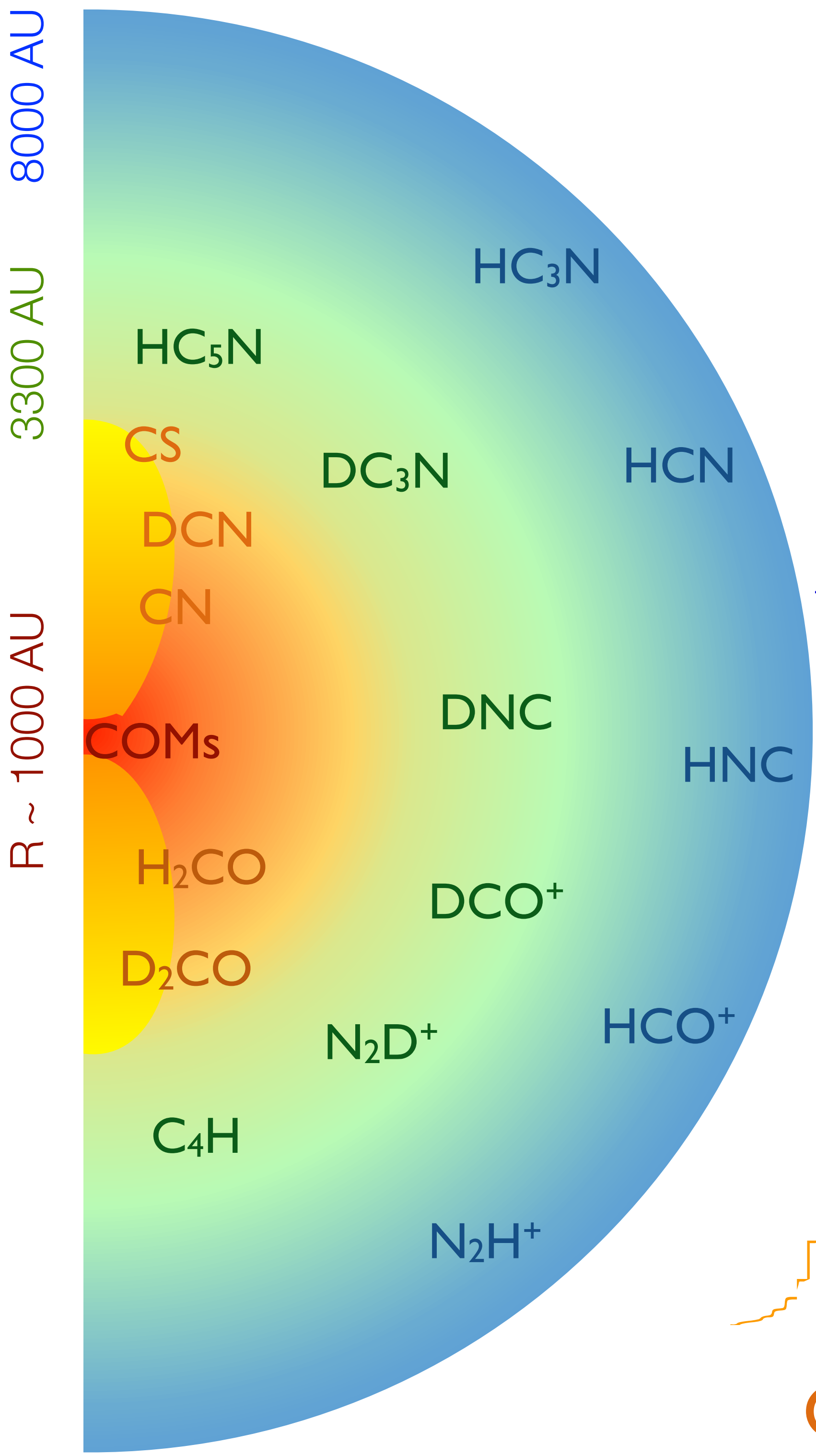


DCO^+

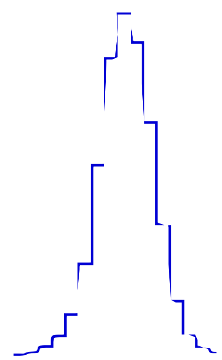
$$\langle \mathrm{FWHM} \rangle = (2.2 \pm 0.3)\mathrm{km\ s^{-1}}$$

$$\langle \mathrm{T_{ex}} \rangle = (13 \pm 3)\mathrm{K}$$

Spatial analysis - summary



Extended envelope



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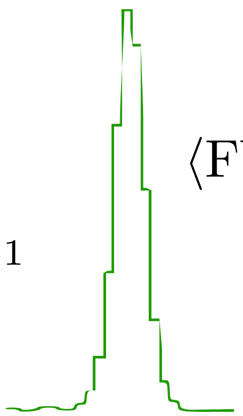

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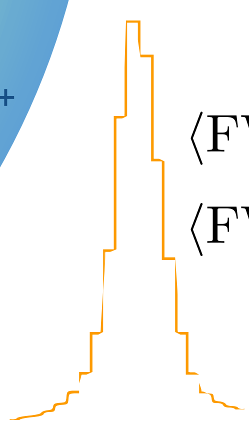
Envelope + outflow / hot core



CN

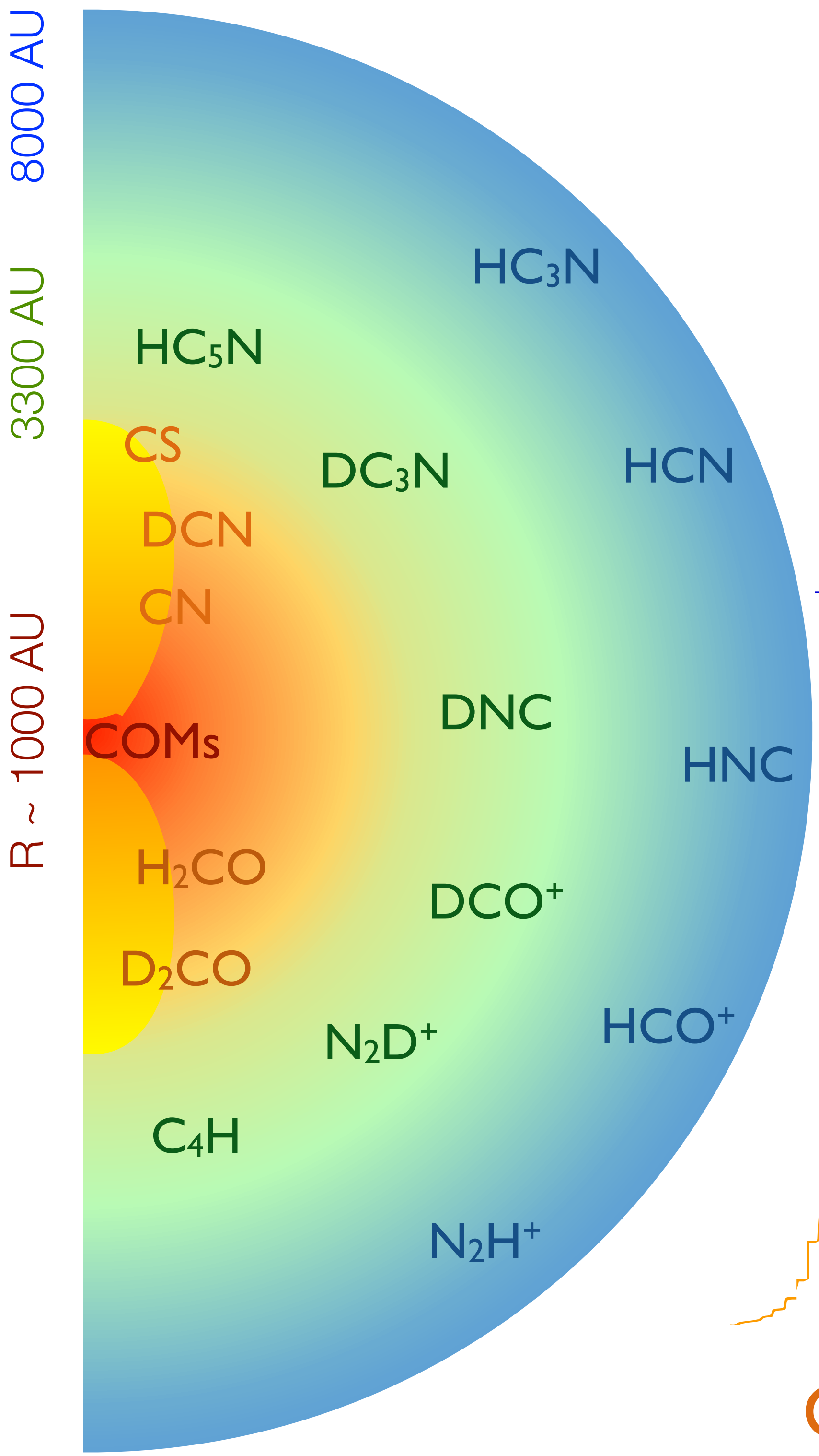
$$\langle \mathrm{FWHM_n} \rangle = (2.6 \pm 0.2)\mathrm{km\ s^{-1}}$$

$$\langle \mathrm{FWHM_b} \rangle = (8.9 \pm 0.5)\mathrm{km\ s^{-1}}$$

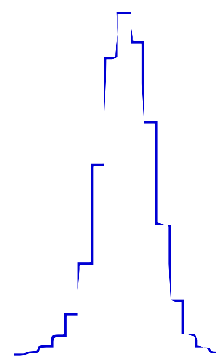
$$\langle \mathrm{T_{ex,n}} \rangle = (14 \pm 2)\mathrm{K}$$

$$\langle \mathrm{T_{ex,b}} \rangle = (17 \pm 2)\mathrm{K}$$

Spatial analysis - summary



Extended envelope



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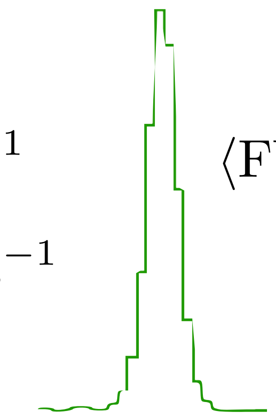

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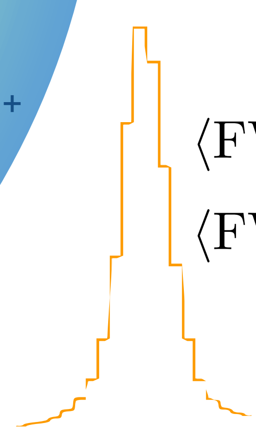

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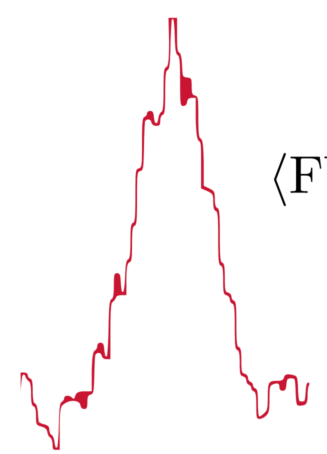
Hot core

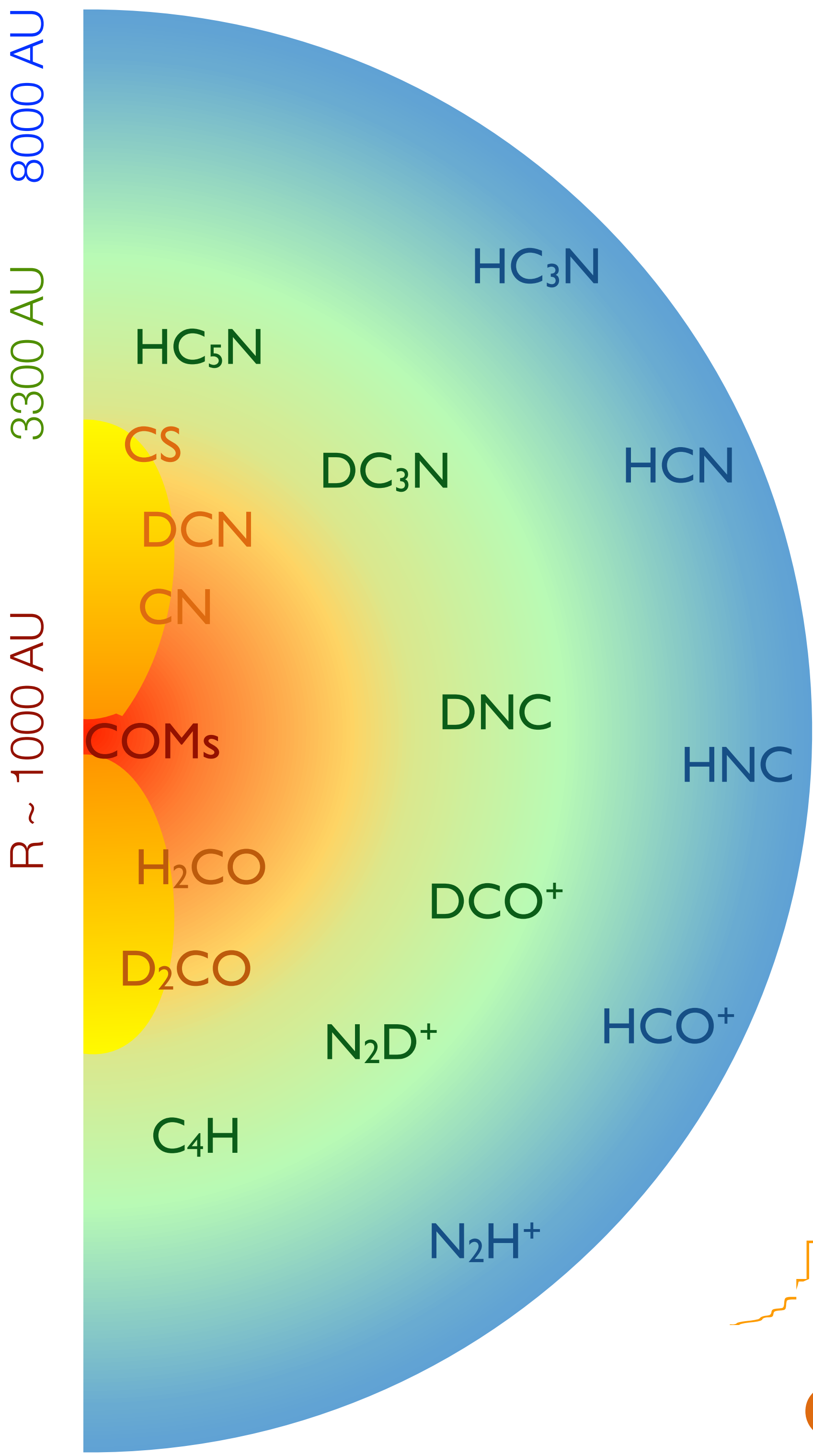


CH_3OH

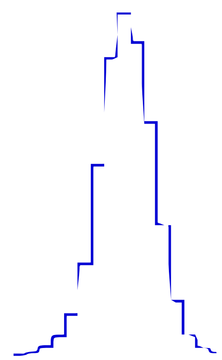
$$\langle \mathrm{FWHM} \rangle = (3.3 \pm 0.3)\mathrm{km\ s^{-1}}$$

$$\langle \mathrm{T_{ex}} \rangle = (127 \pm 35)\mathrm{K}$$

Spatial analysis - summary



Extended envelope



HNC

$\langle \mathrm{FWHM_n} \rangle = (2.9 \pm 0.)\mathrm{km\ s^{-1}}$

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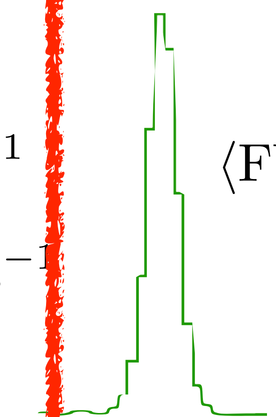
Inner envelope

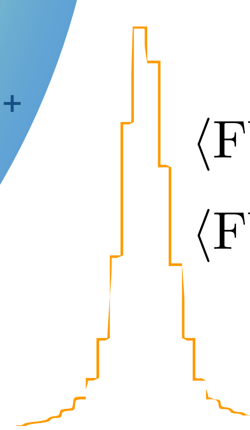


DCO^+

$\langle \mathrm{FWHM} \rangle = (2.2 \pm 0.3)\mathrm{km\ s^{-1}}$

$\langle \mathrm{T_{ex}} \rangle = (13 \pm 3)\mathrm{K}$

Envelope + outflow / hot core



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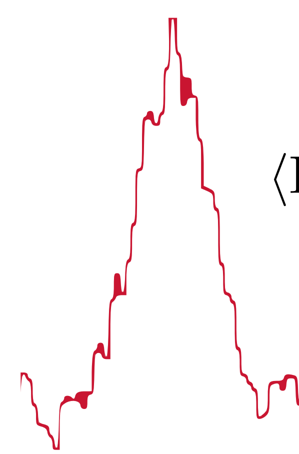
Hot core



CH_3OH

$\langle \mathrm{FWHM} \rangle = (3.3 \pm 0.3)\mathrm{km\ s^{-1}}$

$\langle \mathrm{T_{ex}} \rangle = (127 \pm 35)\mathrm{K}$

We have found the pristine gas

Composition

N_2D^+
DNC
NH_2D
DC_3N
DCO^+
C_3HD
CH_2DCCH
HDCS

N_2H^+
HC_5N
HCCNC

c-C_3H
C_4H

Characteristics

- High density ~6x10^7 cm^{-3}
- High-level of depletion

$$f_D = \frac{x(C^{17}O)_{can}}{x(C^{17}O)_{obs}} = 16$$

- T ~ 12-13 K
- Mean FWHM = 1.9 km s^{-1}
- Low deuteration level ~6.10^{-3}

Comparison of the abundances

Dark clouds

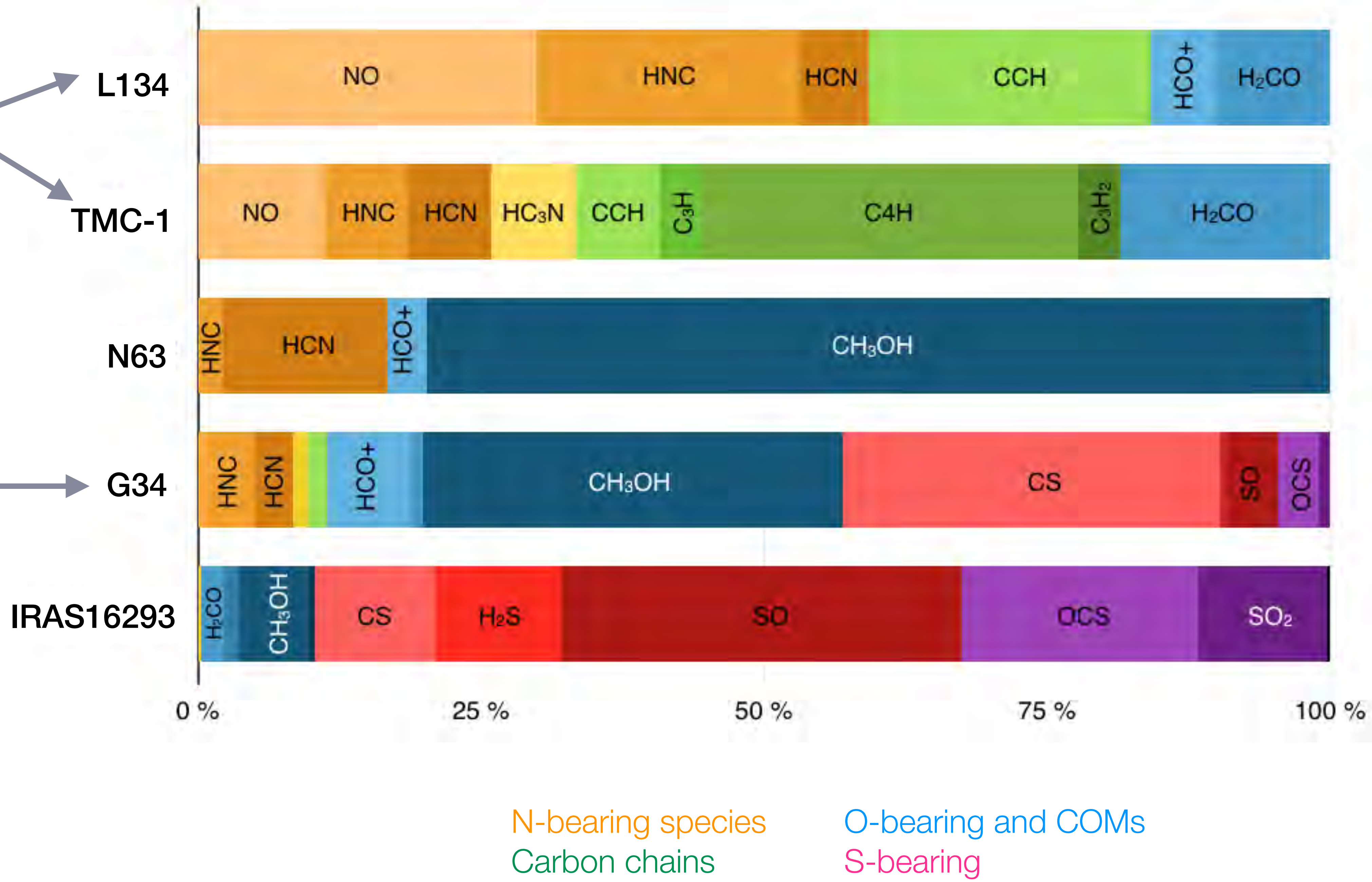
Collated by Garrod et al. 2007

Hot core

Mookerjea et al. 2007

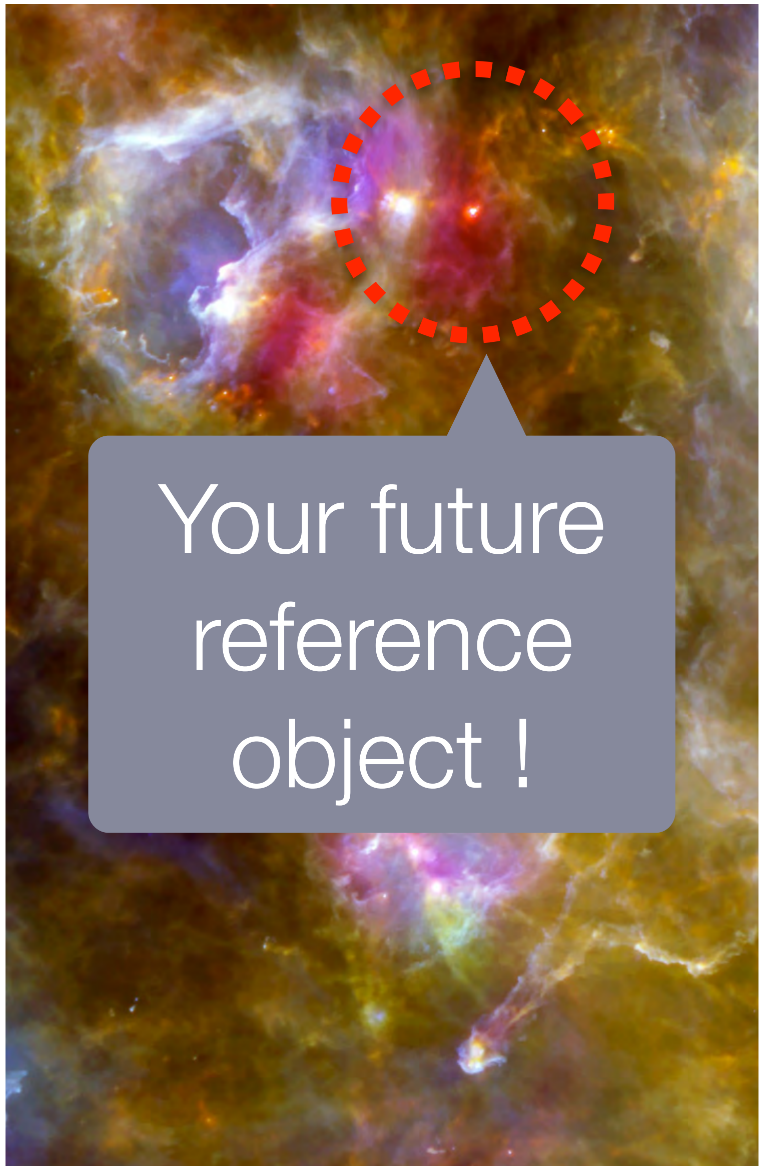
Hot corino

Cazaux et al. 2003
Wakelam et al. 2003
Jorgensen et al. 2004
Bottinelli et al. 2007
Stäuber et al. 2011



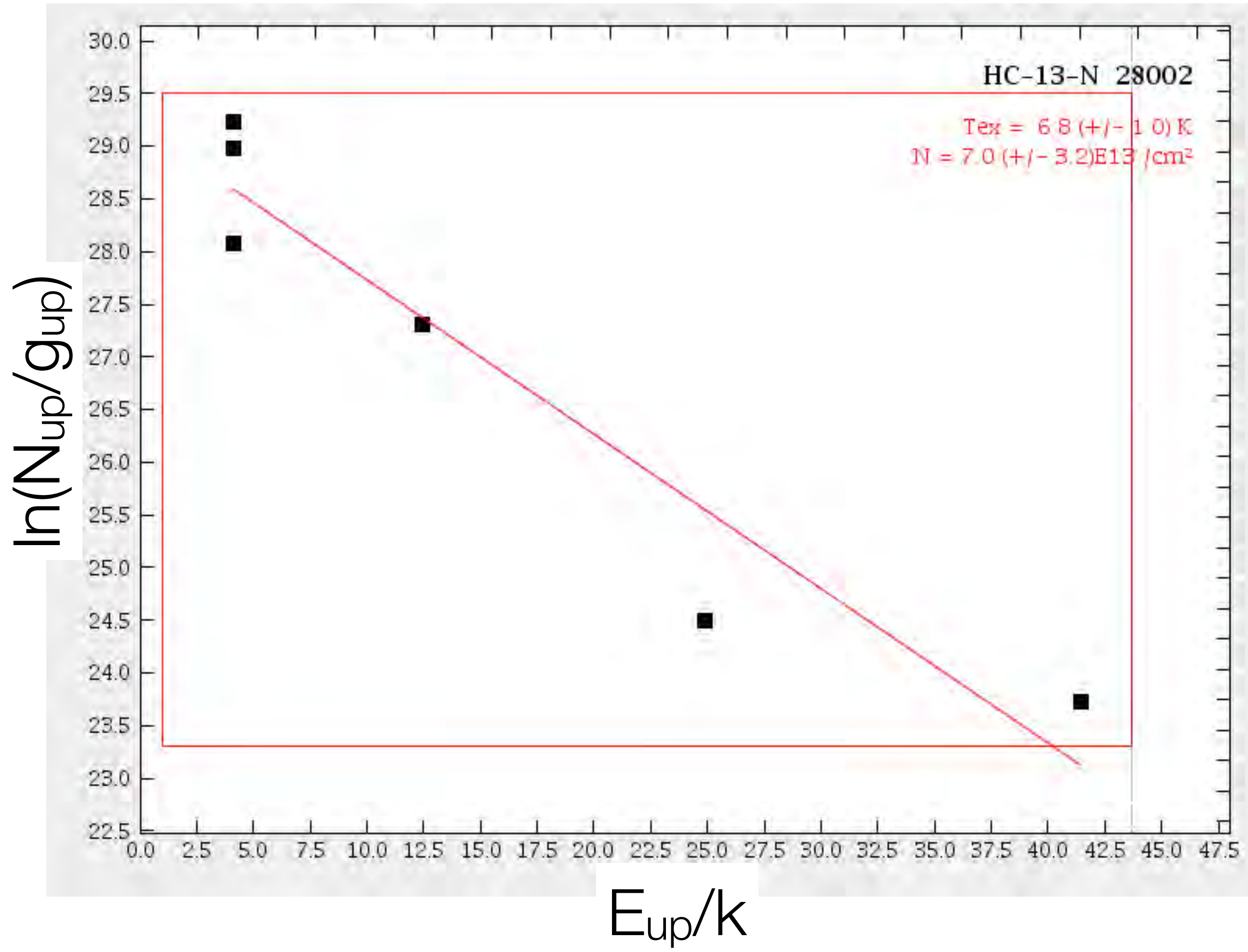
CygX-N63 is a **nascent hot core**

- N63 is an individual massive Class-0
- Chemical composition intermediate between a dark cloud and a hot core
- Chemically rich but not too much
- Tens of $M_\odot$ of highly depleted material
- Abundances determined for 56 species, including 13 deuterated species



Sarah.Fechtenbaum@obs.u-bordeaux1.fr

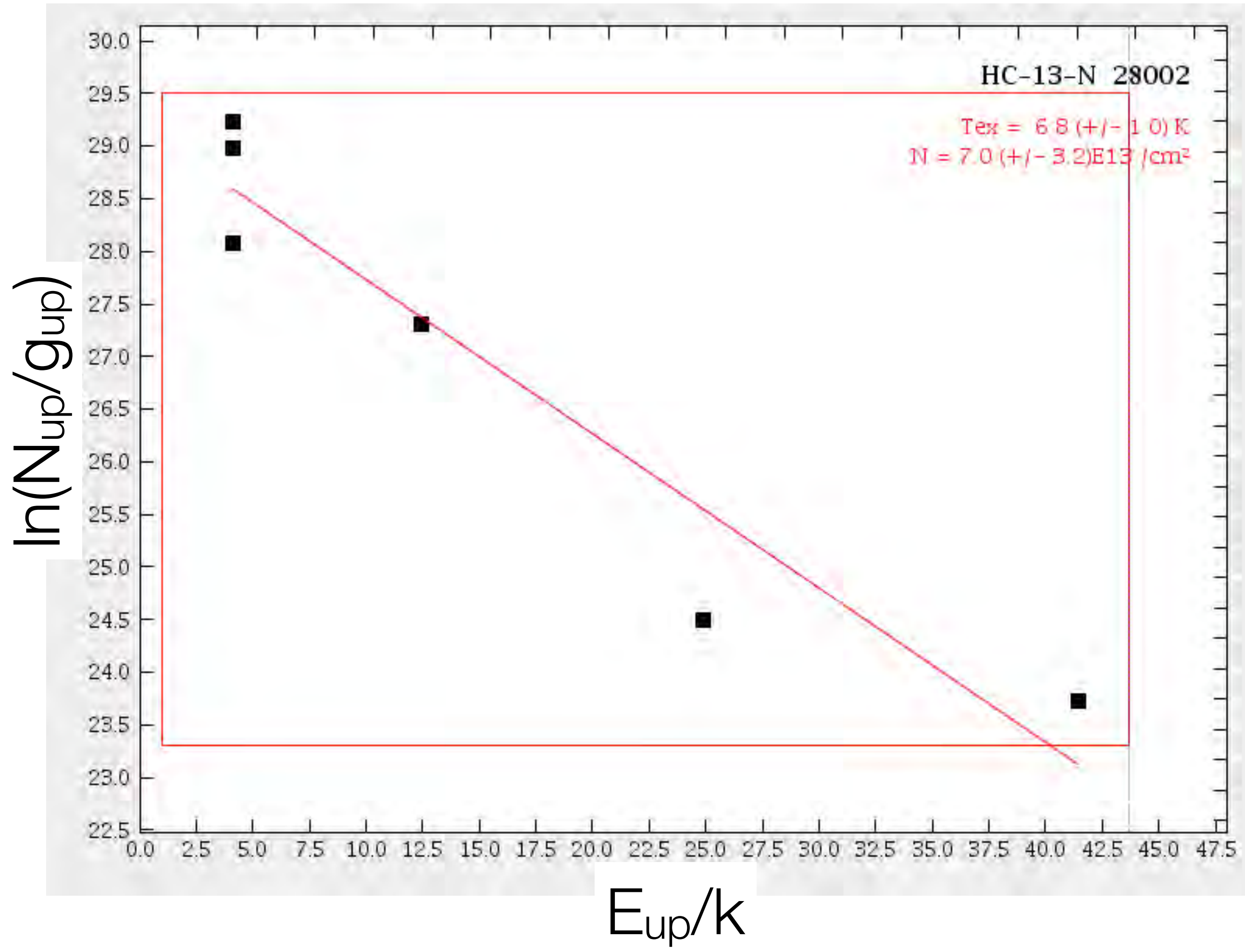
Determination of the column densities



Population diagram of $H^{13}CN$

Determination of the column densities

- Population diagrams

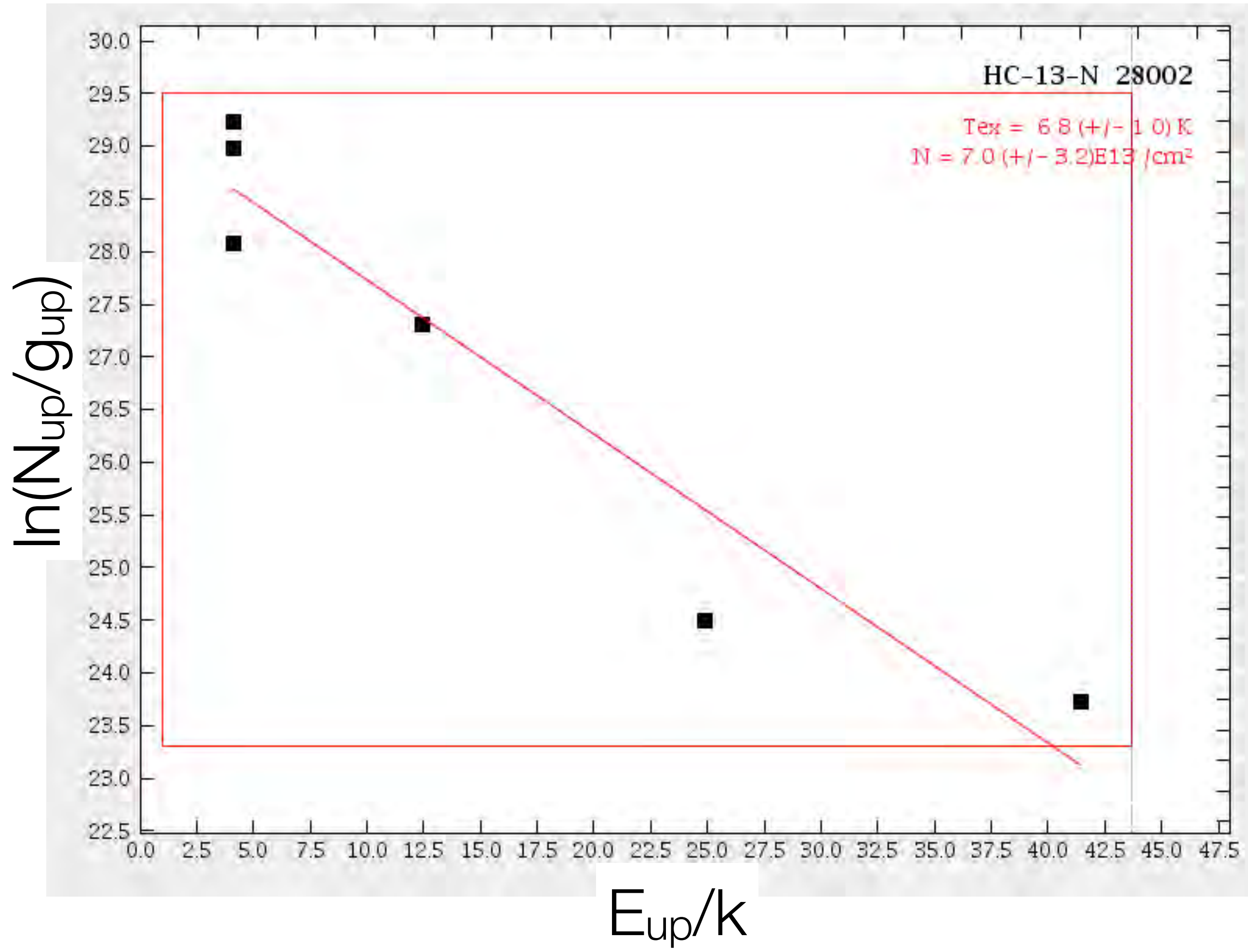


Population diagram of $H^{13}CN$

Determination of the column densities

- Population diagrams

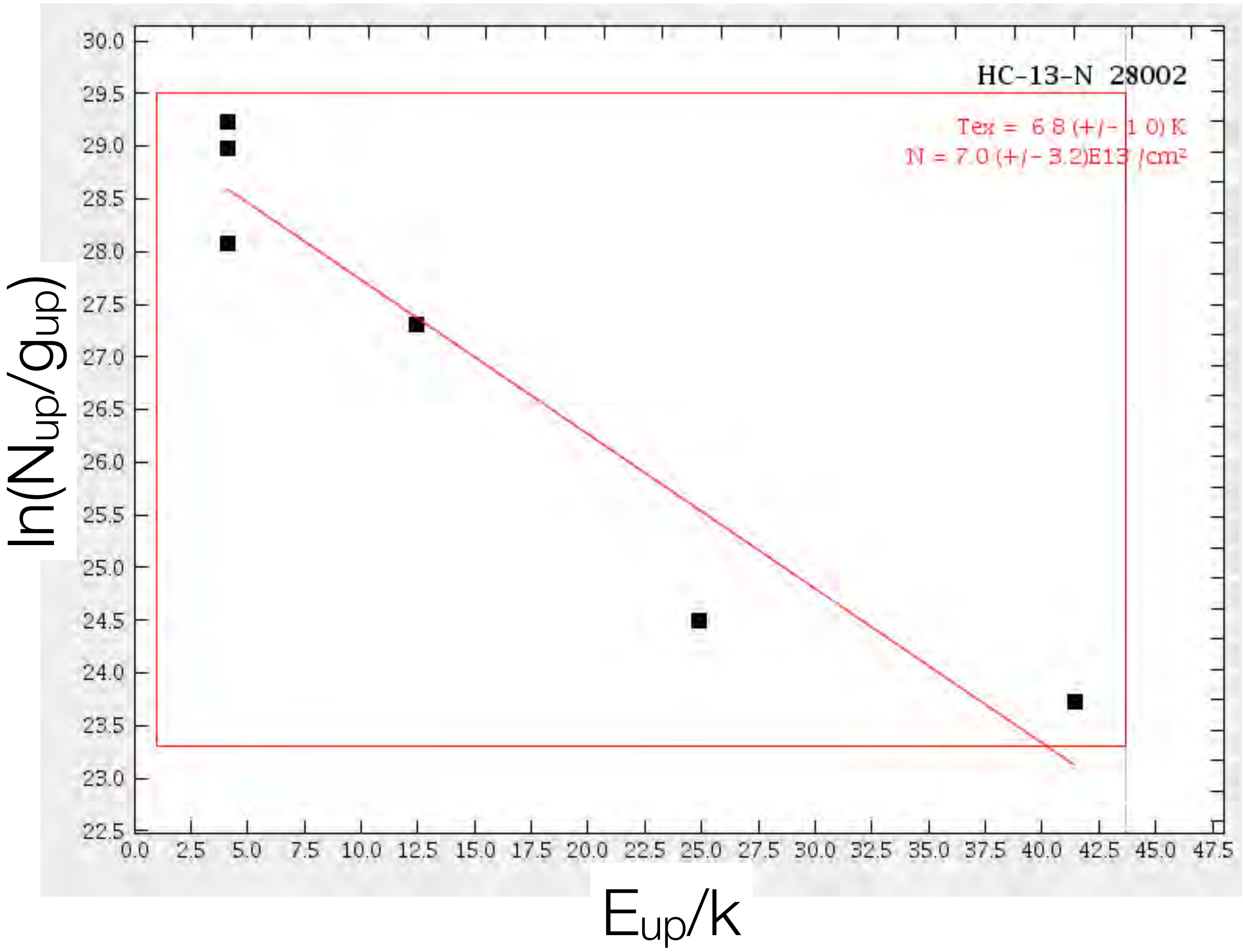
- Detection of 37 rare isotopologues



Population diagram of $H^{13}CN$

Determination of the column densities

- Population diagrams
- Detection of 37 rare isotopologues
- LTE-model of the software CASSIS estimates the opacity



Population diagram of $H^{13}CN$

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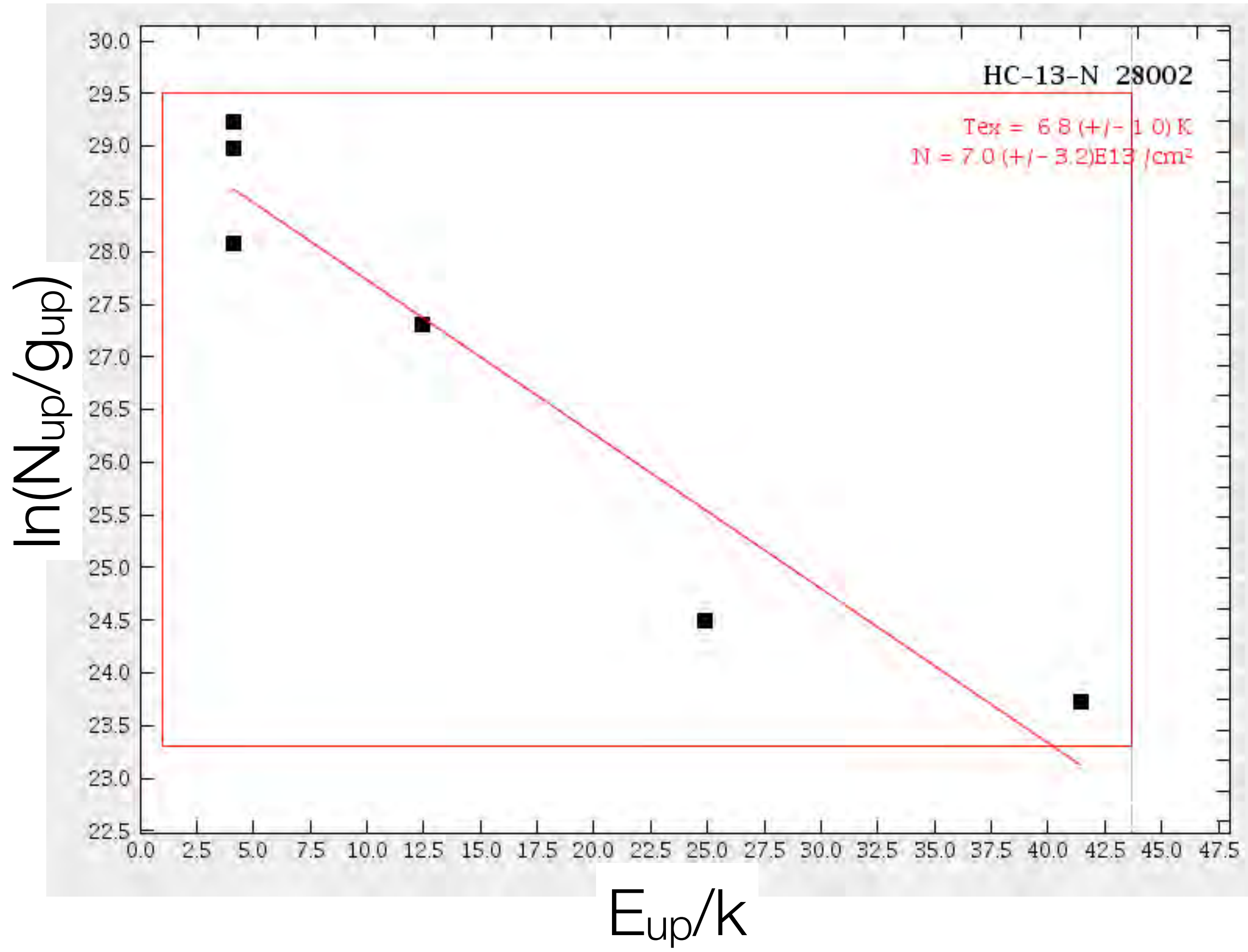

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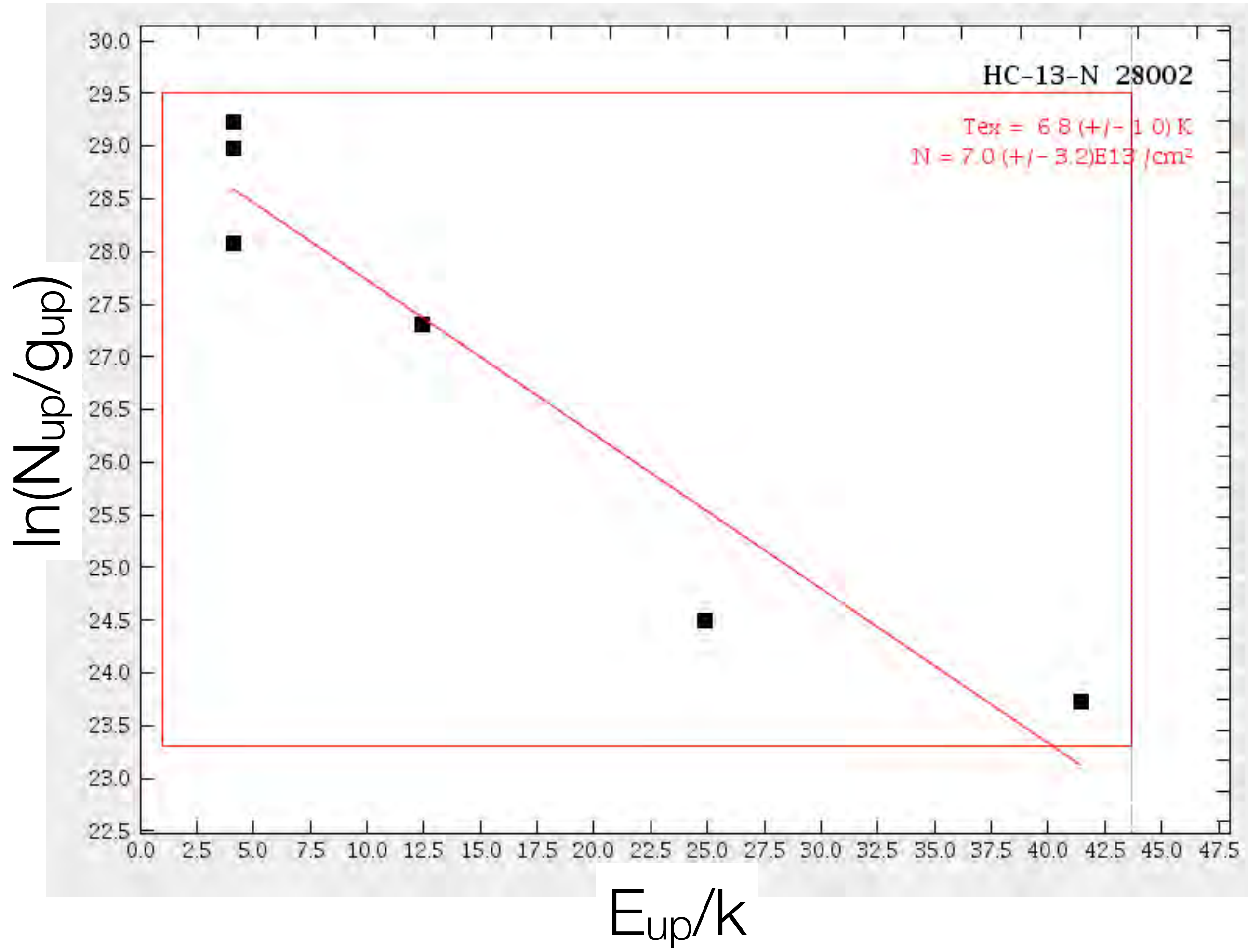
- Emission size estimation

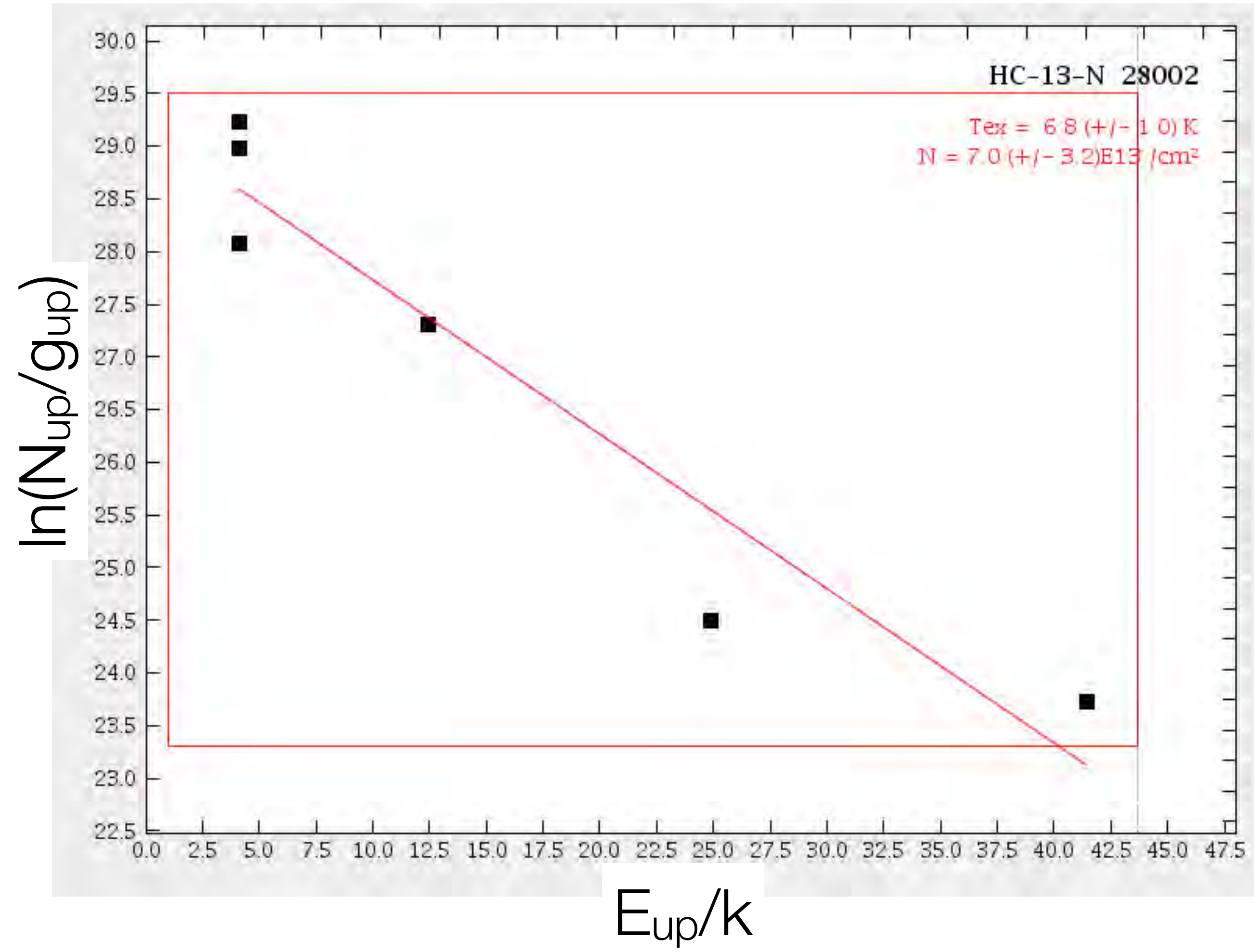


Population diagram of $H^{13}CN$

Determination of the column densities

- Population diagrams
- Detection of 37 rare isotopologues
- LTE-model of the software CASSIS estimates the opacity
- High density ~10^6 - 10^7 cm^{-3} => probable LTE
- Emission size estimation

=> Reliable column densities



Population diagram of $H^{13}CN$

Determination of the abundances

Global abundances

~44 $M_{\odot}$ in 2500 AU

Duarte-Cabral et al. 2013

=> global $n(H_2)$

=> Reliable global abundances

Determination of the abundances

Global abundances

~44 $M_\odot$ in 2500 AU

Duarte-Cabral et al. 2013

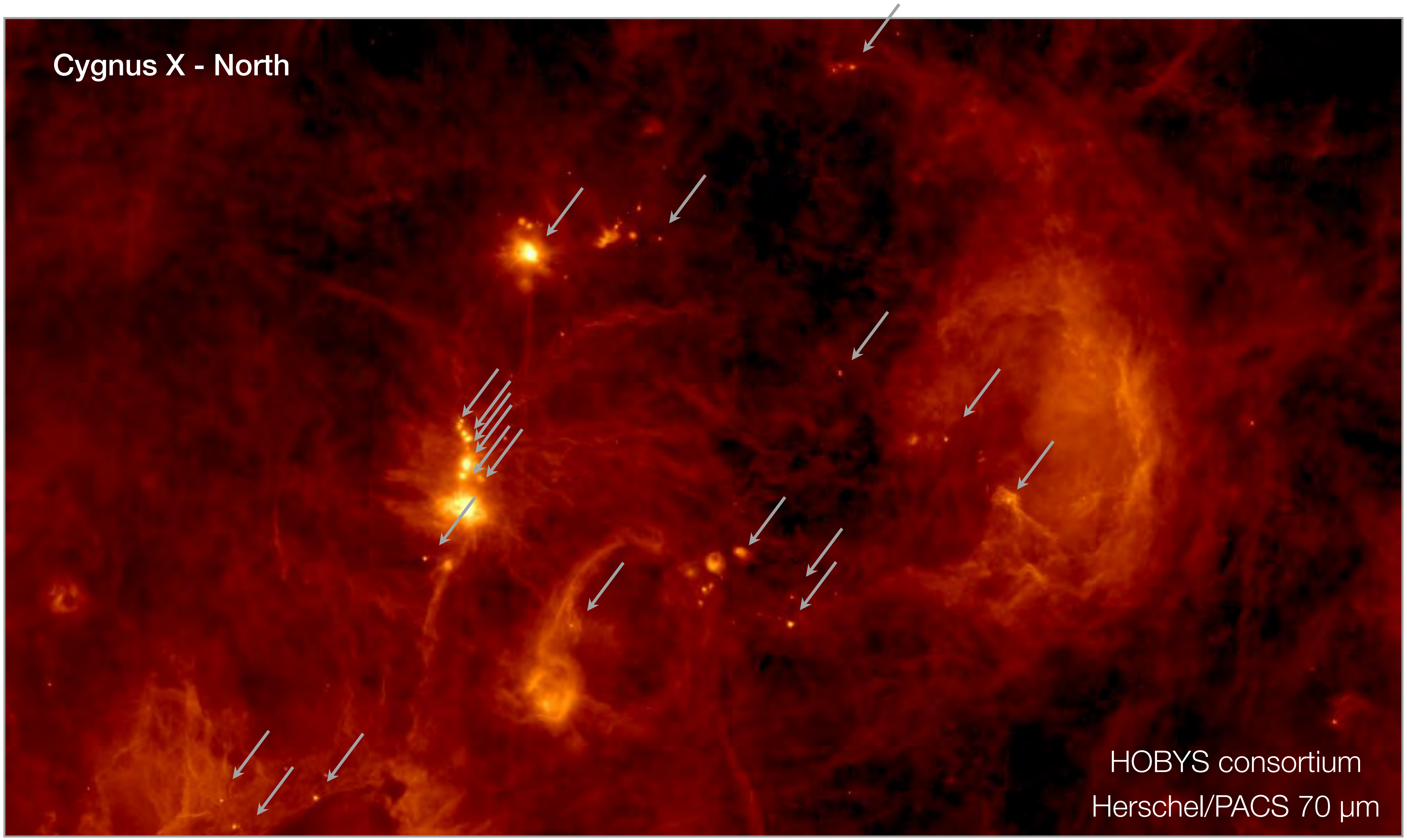
=> global $n(H_2)$

=> Reliable global abundances

Detailed abundances

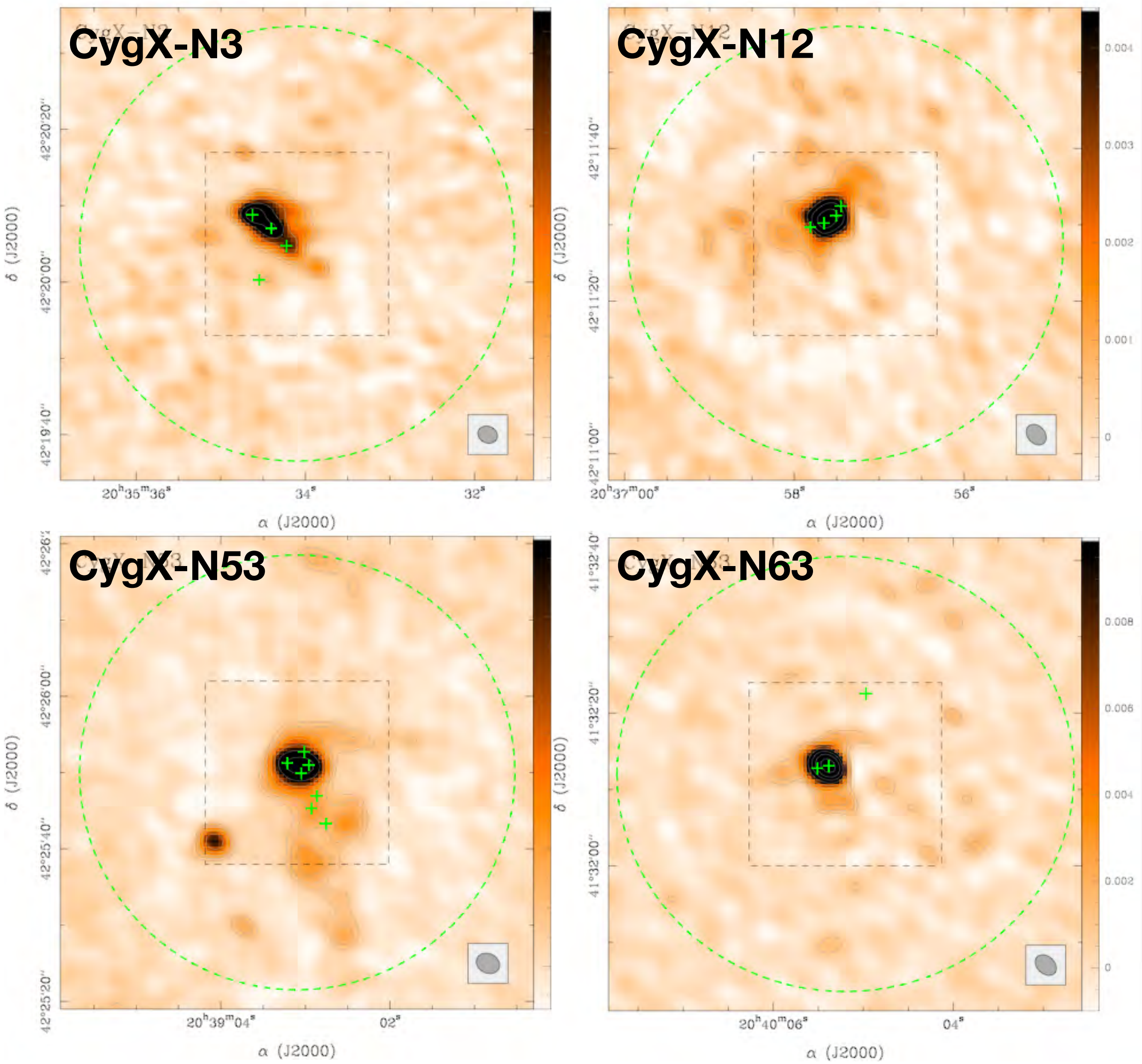
- Determination of the emission size
- $n(H_2)$ determined at different r with $\rho \propto r^{-2}$

The Cygnus-X region



Search for massive dense cores

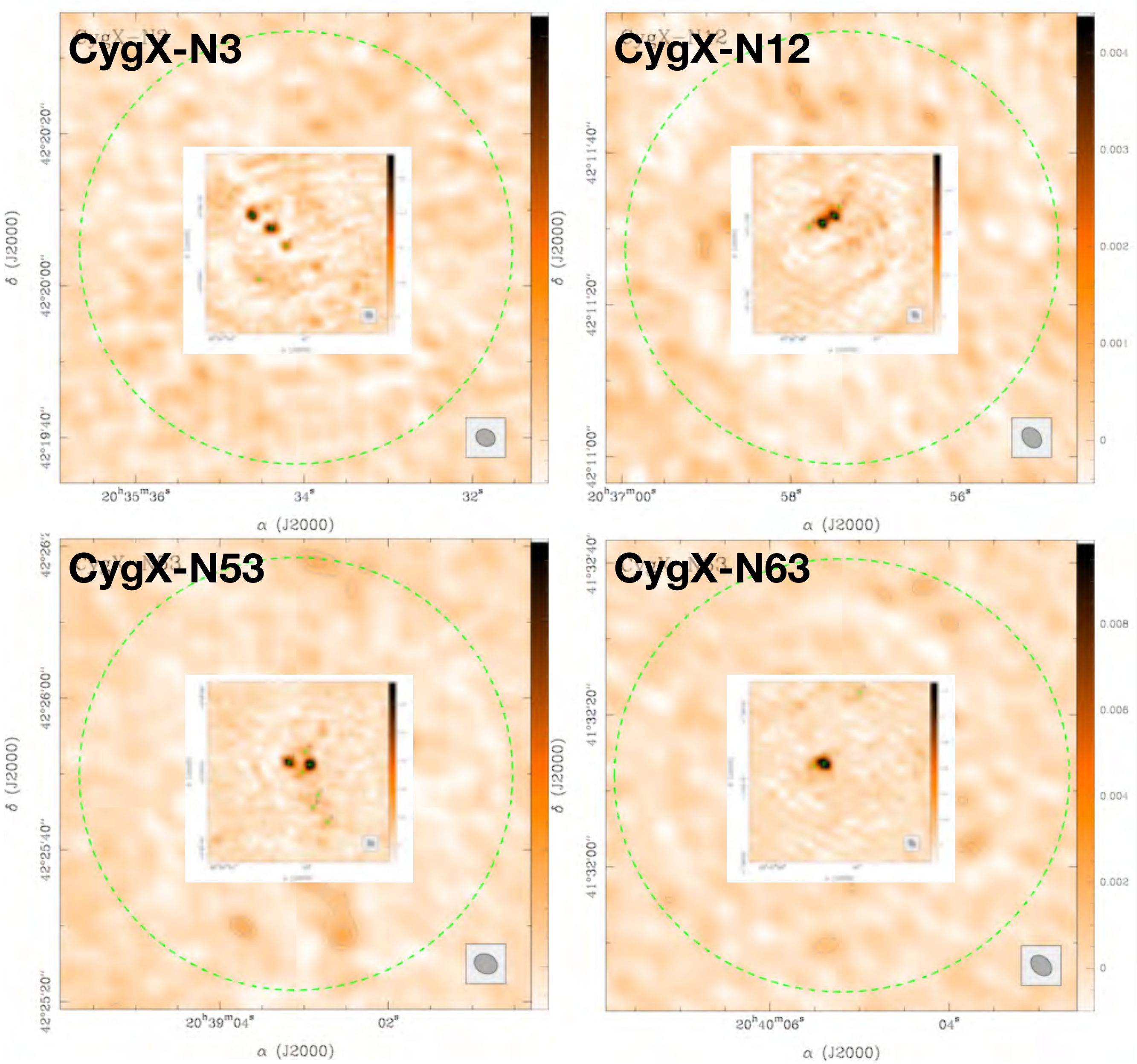
PdBI observations



Bontemps et al. 2010

PdBI 3.5 mm
3.2” res. (4500 AU)

PdBI observations

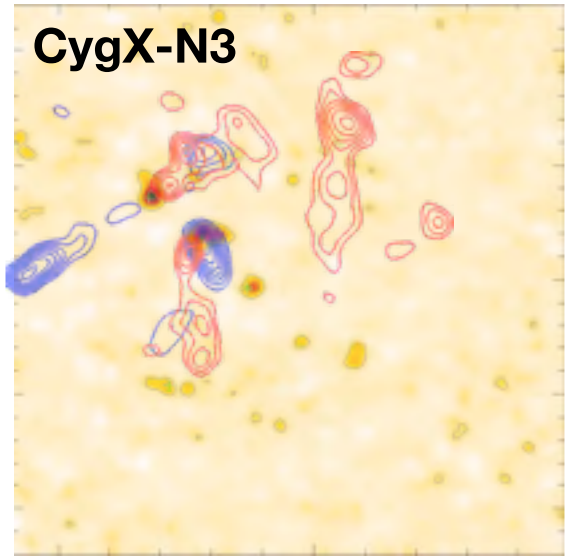


Bontemps et al. 2010

PdBI 3.5 mm
3.2” res. (4500 AU)

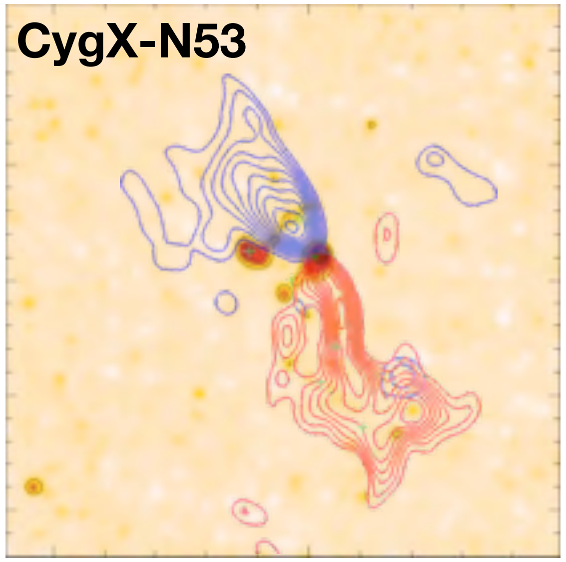
PdBI 1.3 mm
1.1” res. (1500 AU)

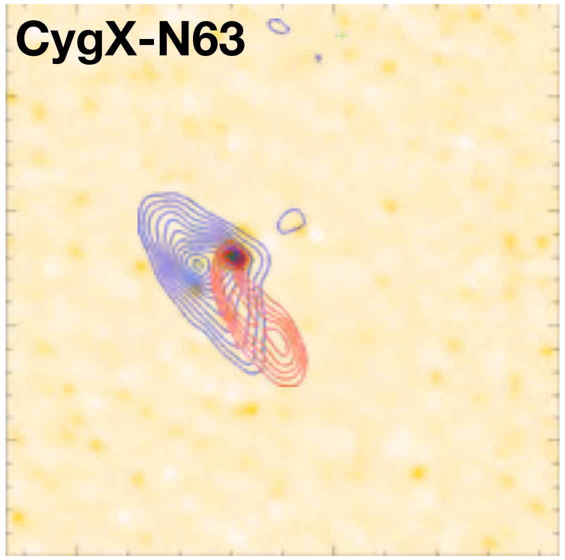
PdBI observations



AB configuration
(500 AU)

PdBI 3.5 mm
3.2” res. (4500 AU)





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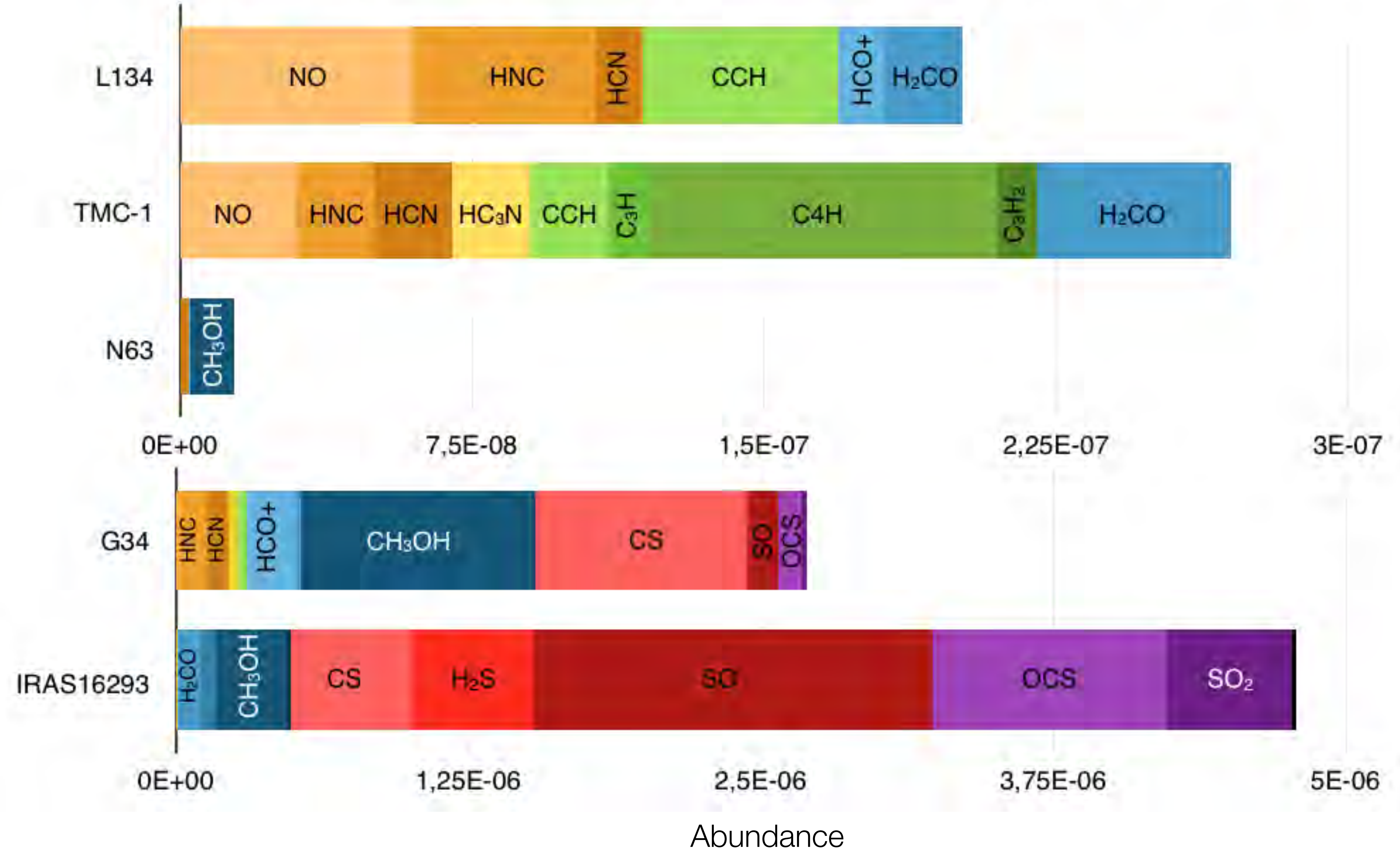
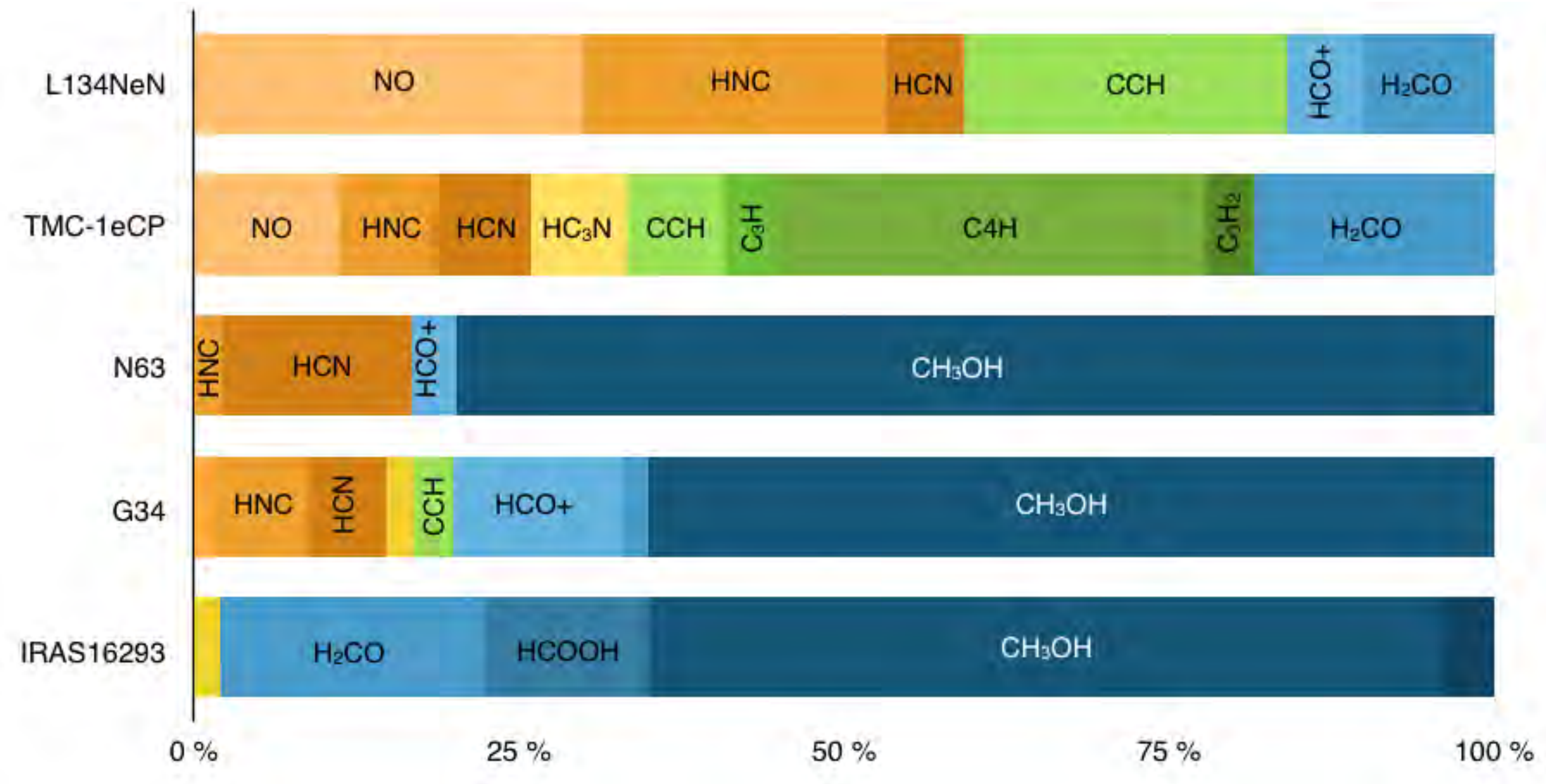
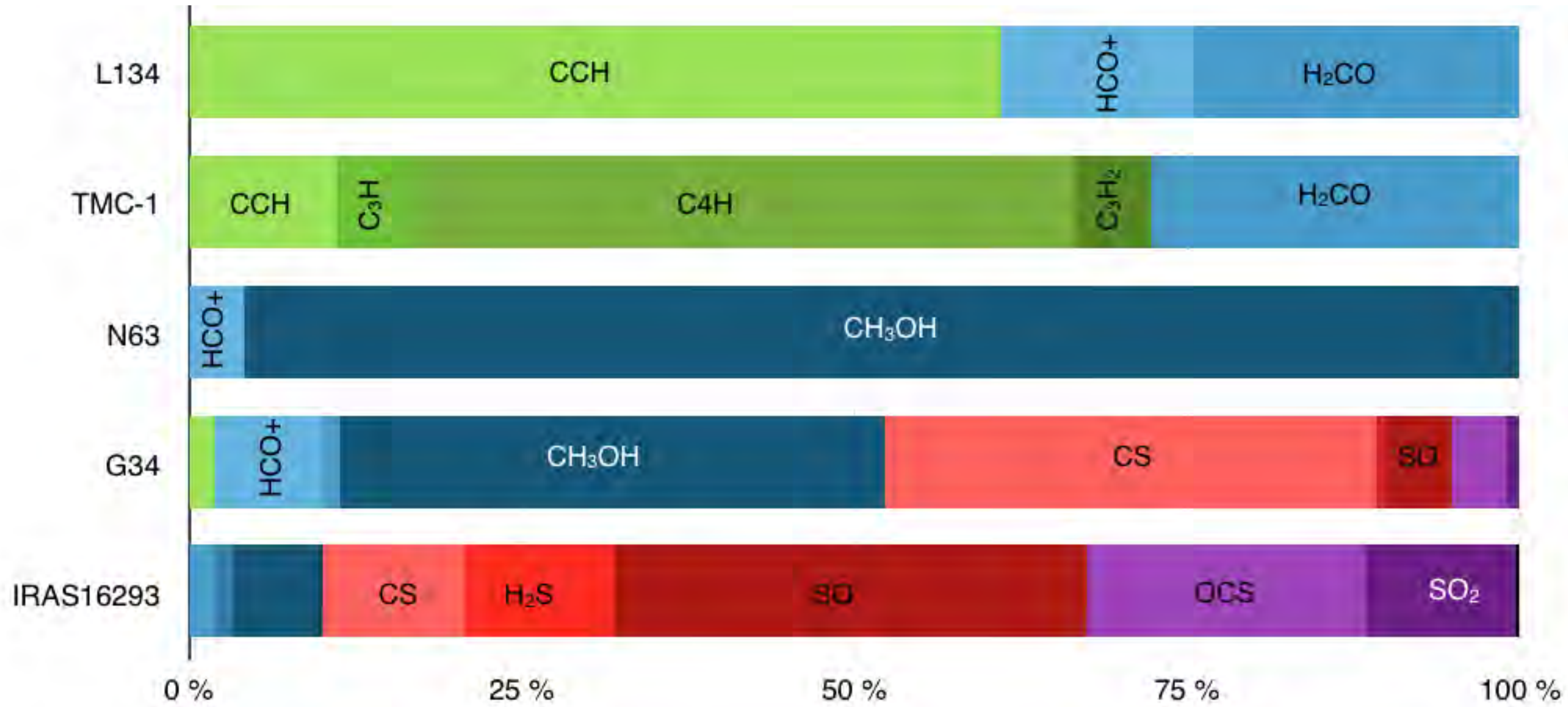
Comparison of the abundances



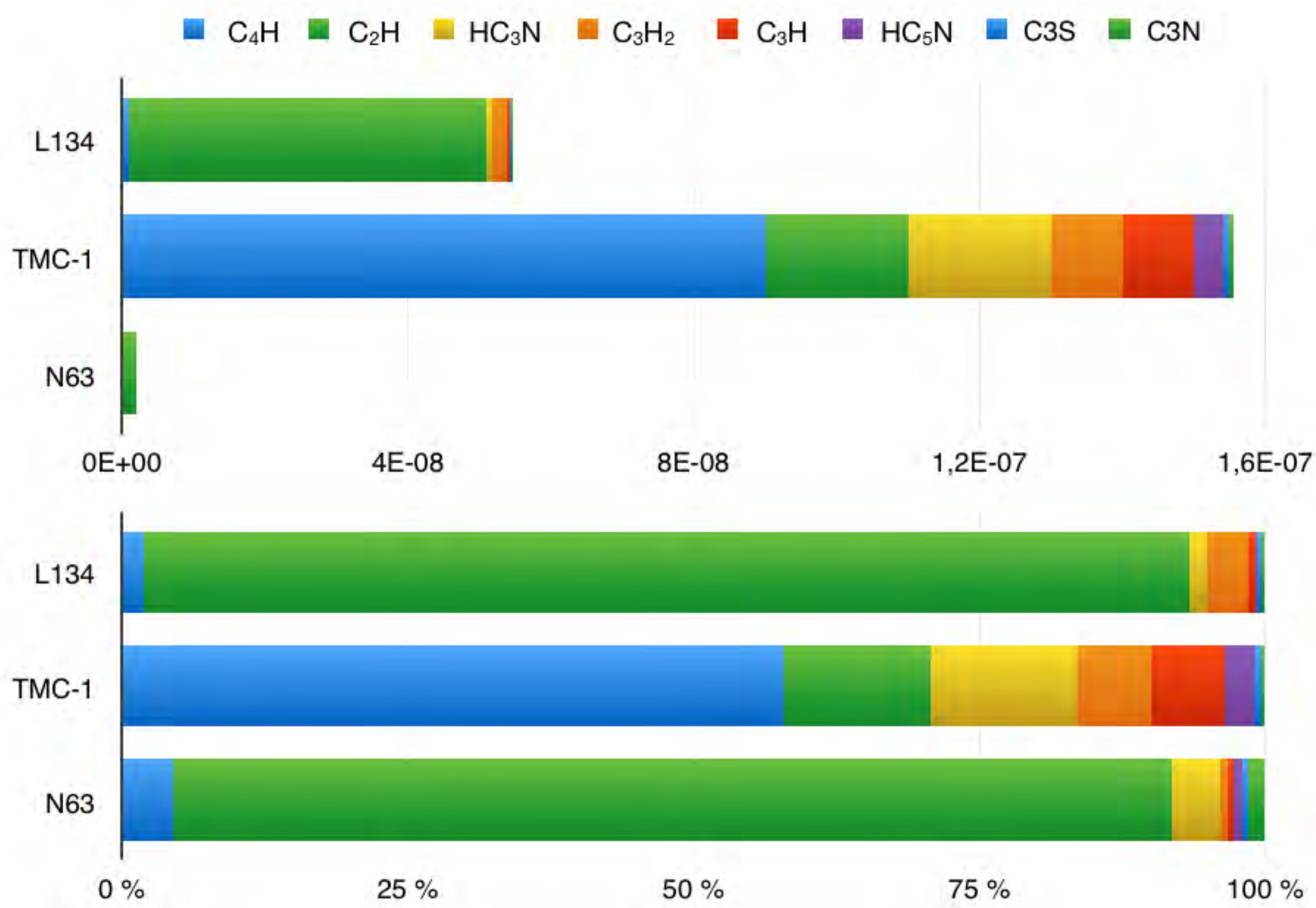
Without S-bearing species



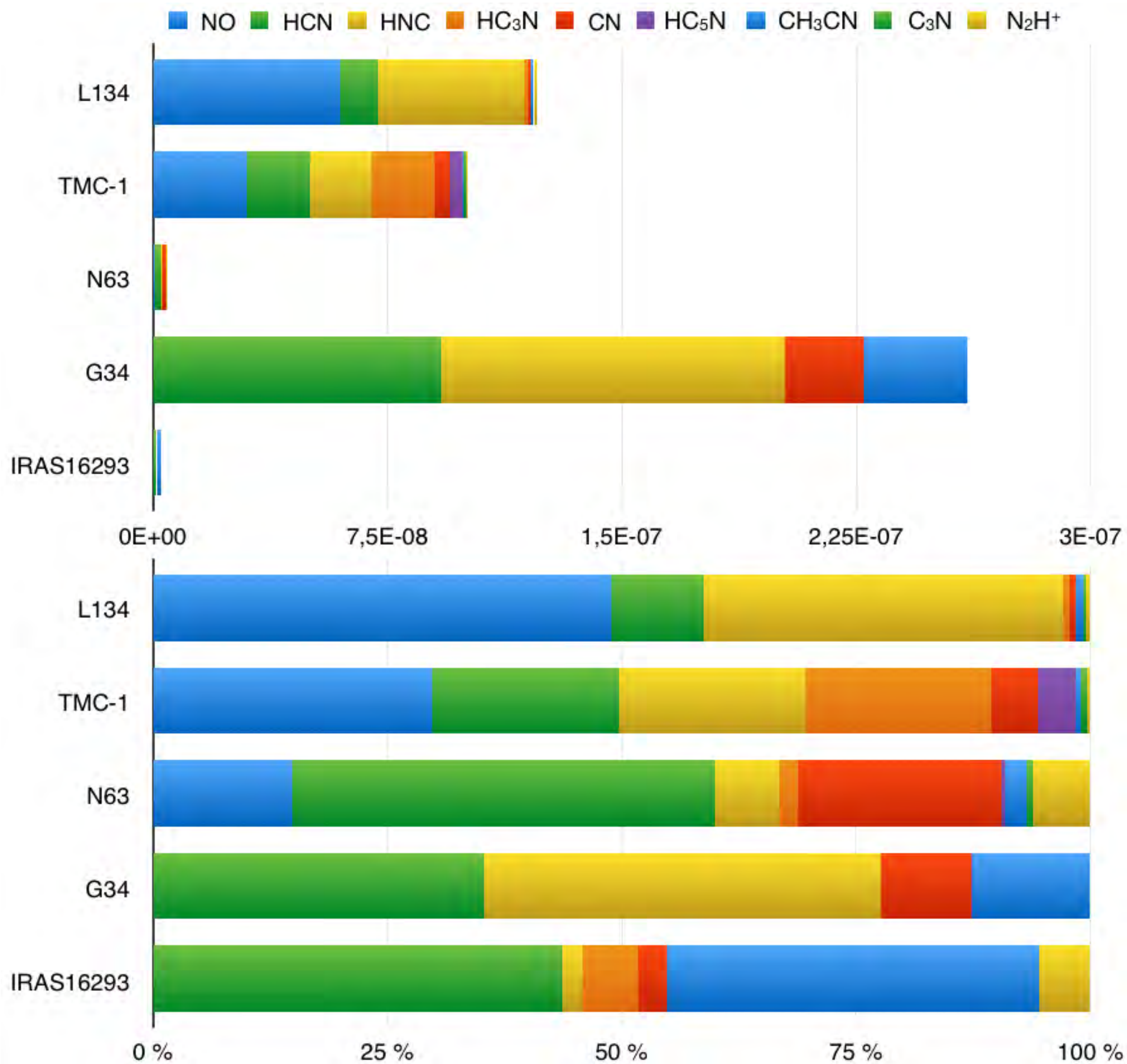
Without N-bearing species



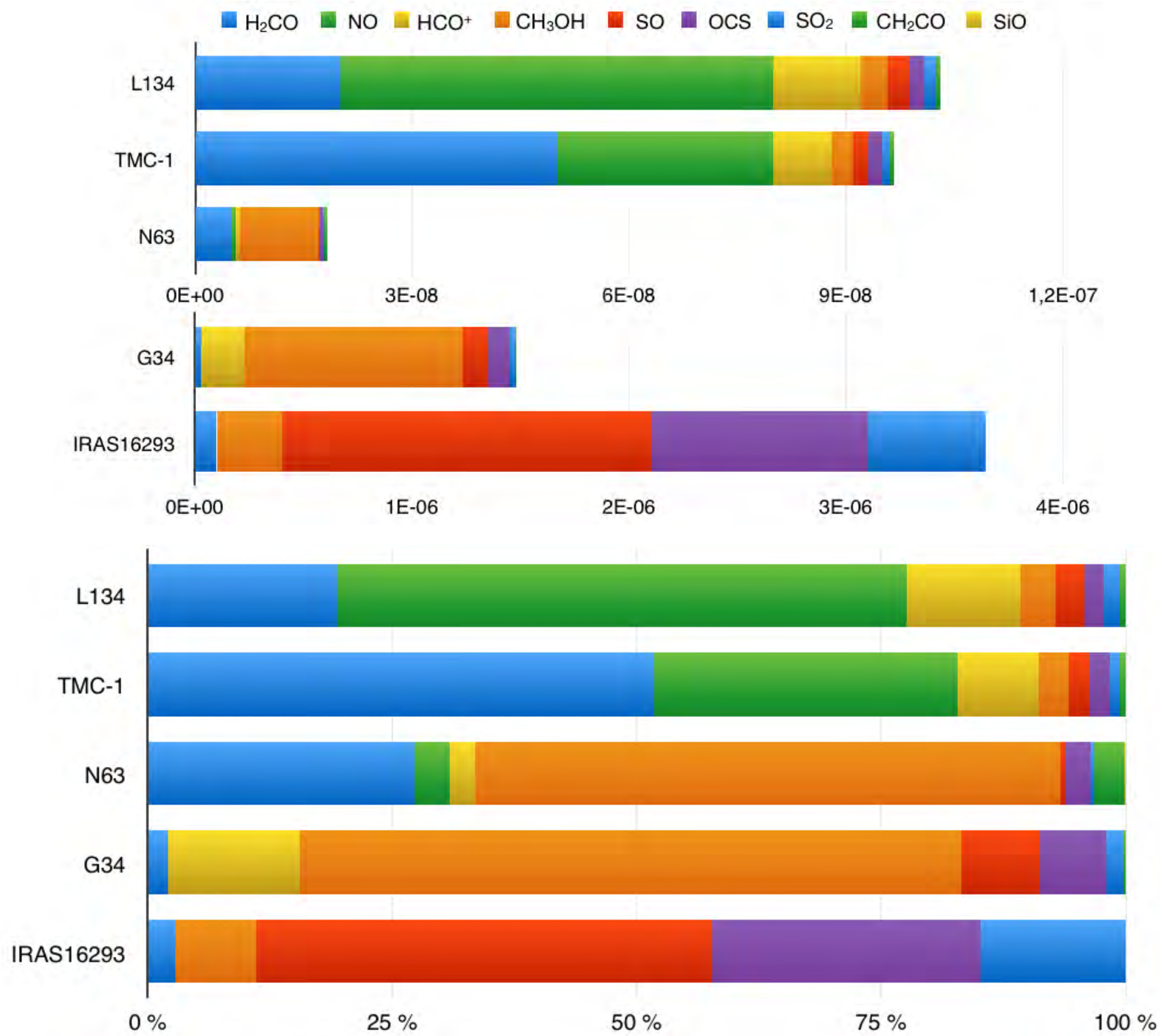
Carbon chains



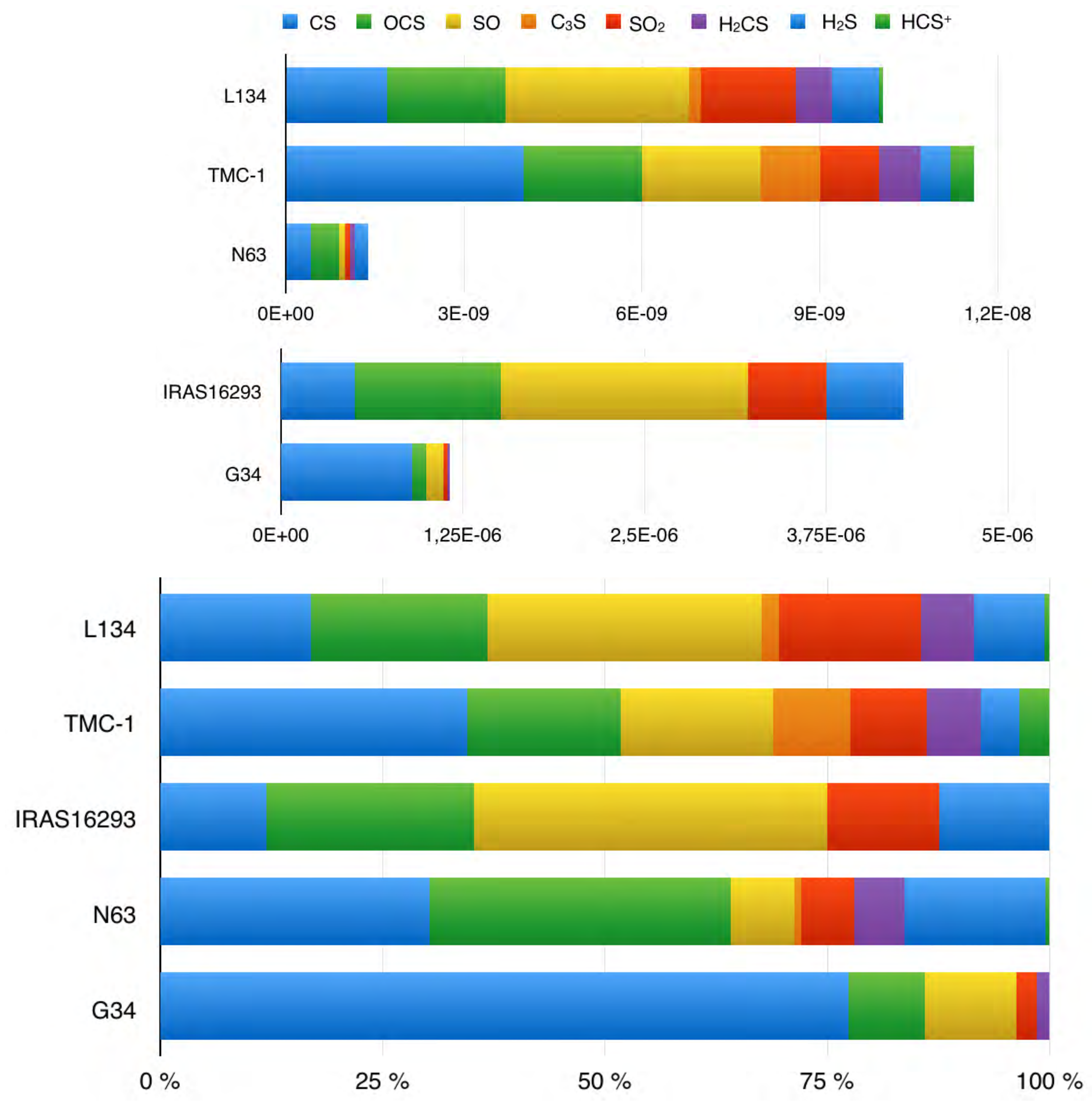
N-bearing species



O-bearing species



S-bearing species



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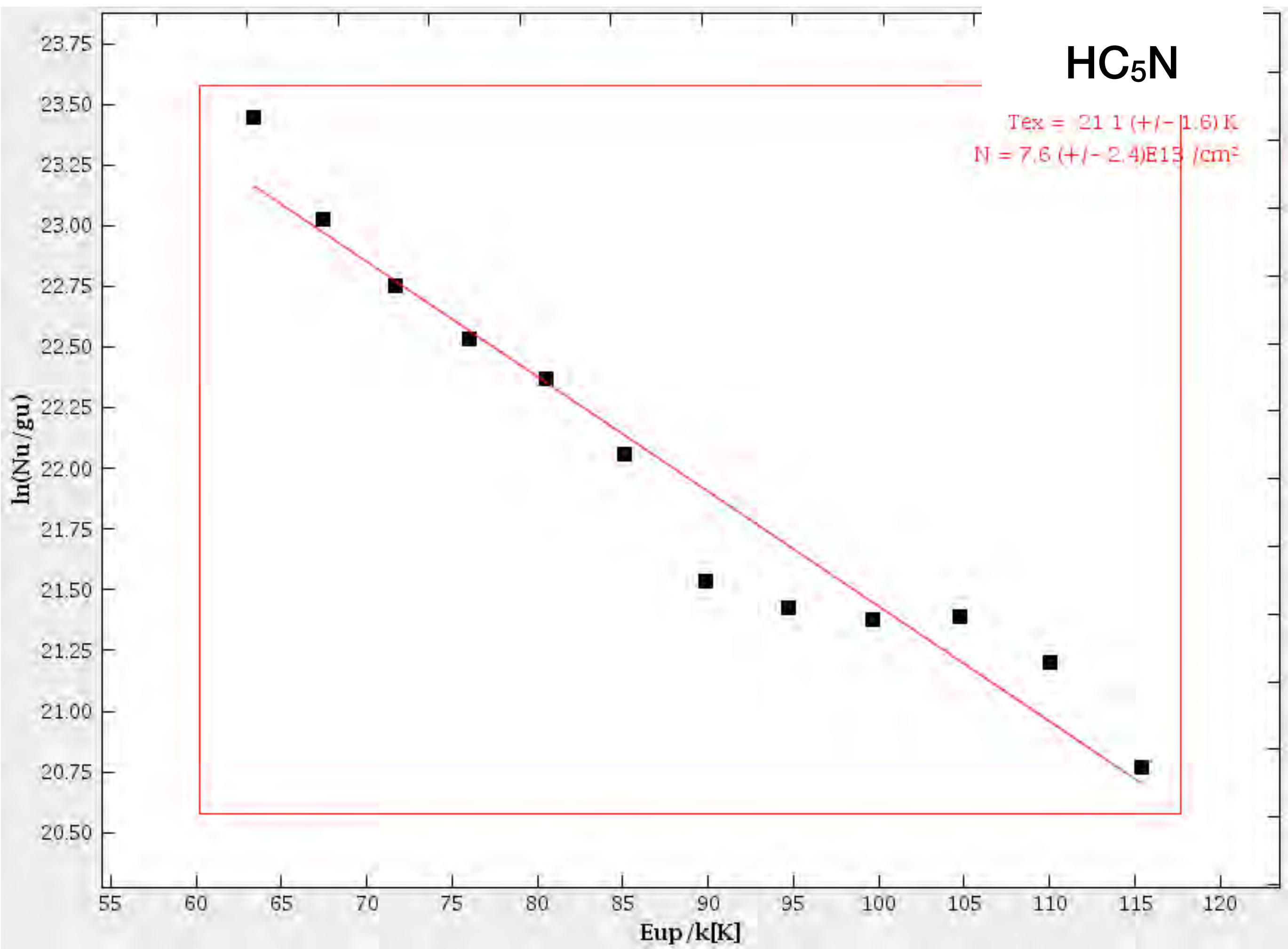

- Local thermodynamical equilibrium (LTE)
- Optically thin lines
- Negligible CMB
- Size of the emission

$$N_u = W \times \frac{8\pi k \nu^2}{hc^3 A_{ul}} \times C_\tau$$

$$ln\frac{N_u}{g_u} = lnN_{tot} - lnQ(T_{ex}) - \frac{E_u}{kT_{ex}}$$