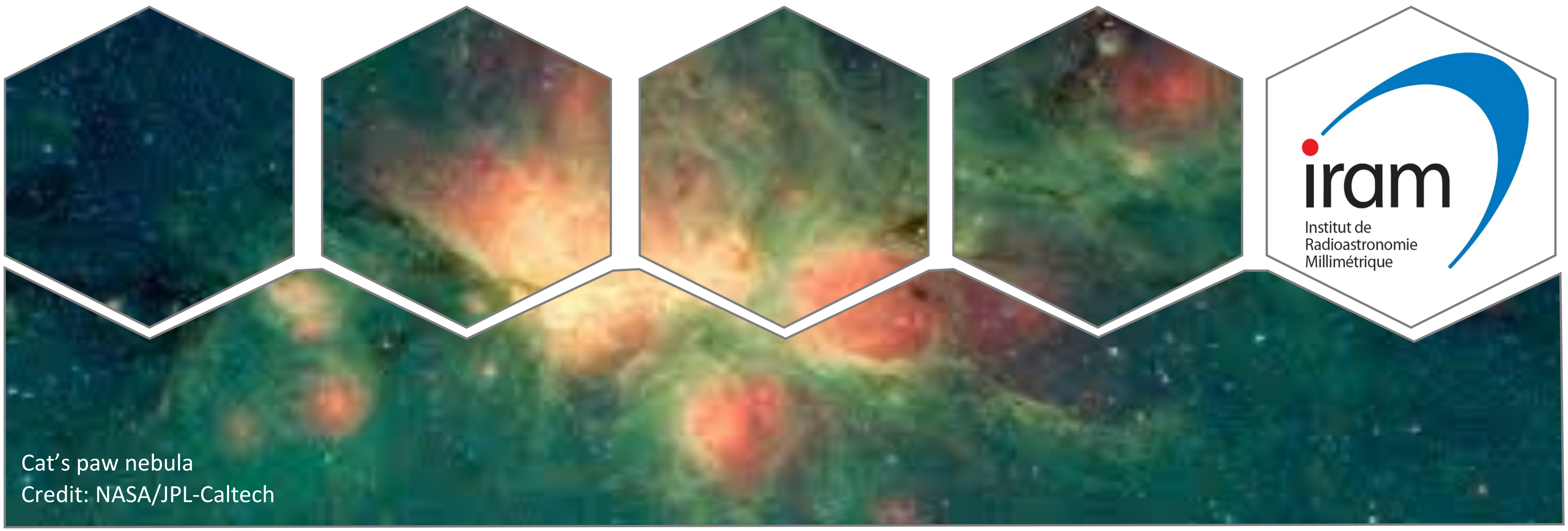
Emerging molecular complexity in the warm gas of young protostars

Laure Bouscasse

IRAM

T. Csengeri, A. Belloche, F. Wyrowski, S. Bontemps, R. Güsten, K. M. Menten

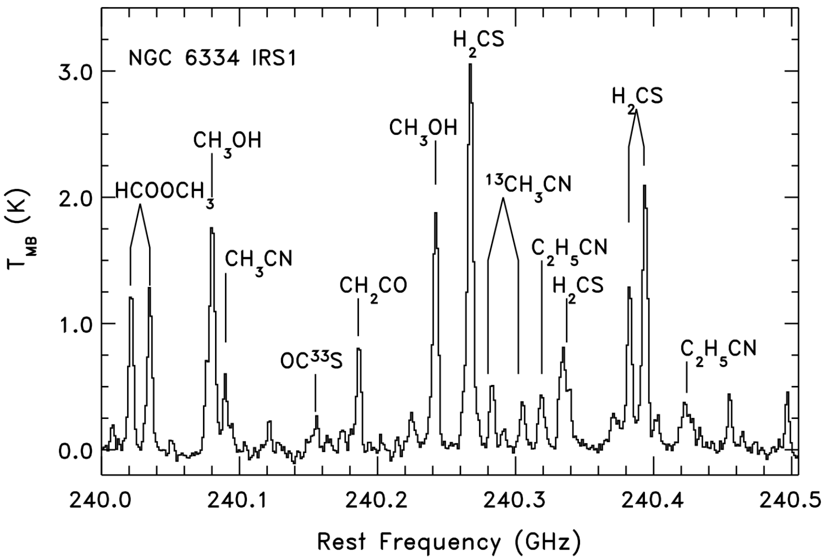


Cat's paw nebula
Credit: NASA/JPL-Caltech

Hot cores: molecular richness

Chemical context

First detections of complex organic molecules (COMs, 6 or more atoms): hot cores



>15 COMs are detected in hot cores (Belloche et al.2013)

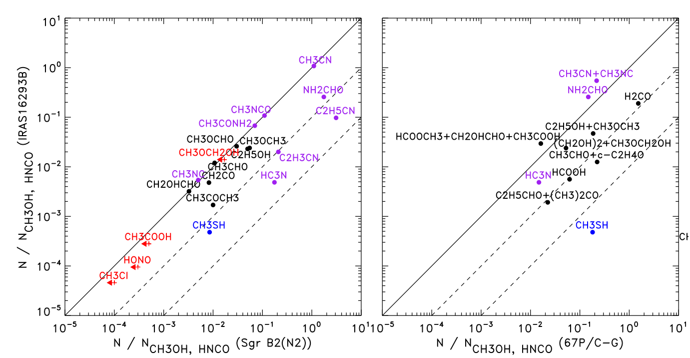
Hot corinos = hot cores in the low-mass regime (Ceccarelli et al. 2000)

Spectra towards NGC6334IRS1 (*Bisschop et al. 2007*)

What conditions determine the molecular richness?

30 Doradus
Credit: Hubble Space Telescope

Origin of the molecular complexity?



Jorgensen et al. 2020

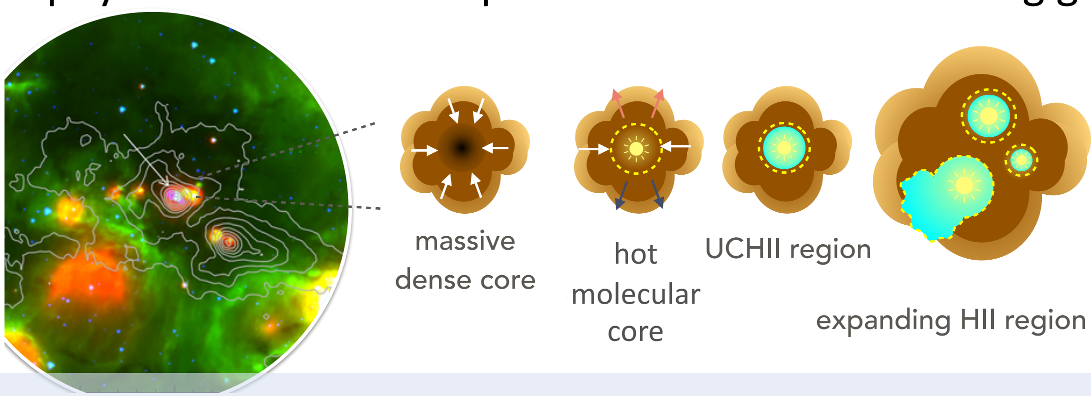
Chemical context

Observations: similarities between hot corinos and comets

→ Chemical heritage?

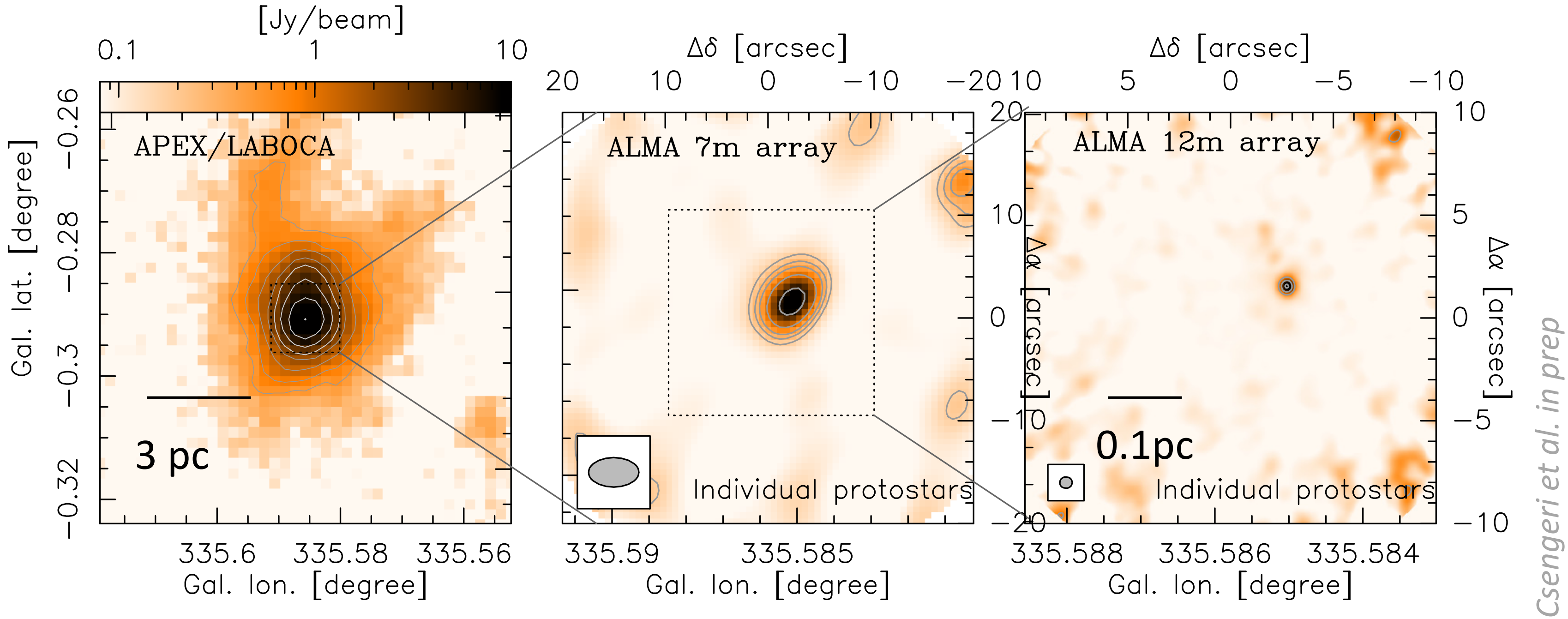
Emergence of hot cores:

- Intensive studies on hot cores but not on the early-stages
- What are the physical and chemical processes in the star-forming gas?



What are the physical properties of the gas during the emergence of the hot cores and the early warm-up phase chemistry?

From clumps to cores: ATLASGAL to SPARKS



Only 6 objects out of >35 protostellar envelopes revealed to have a single object.

→ **Targeted sources**: isolated, massive and non fragmented hot core precursors

Best laboratories to study the warm-up phase chemistry:

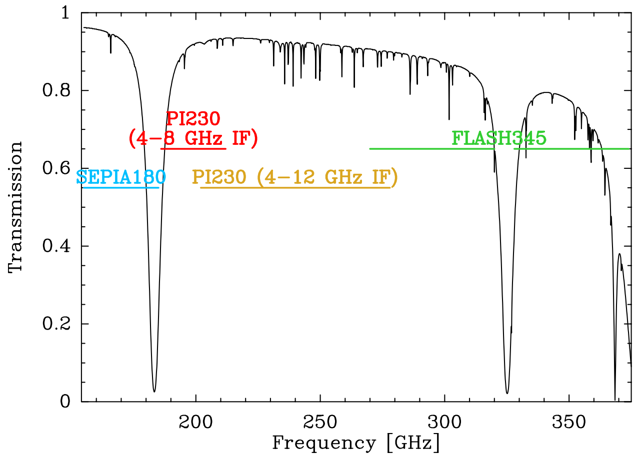
- **Physics of the gas through excitation studies**
- **Chemical composition towards all 6 sources**

Spectral survey

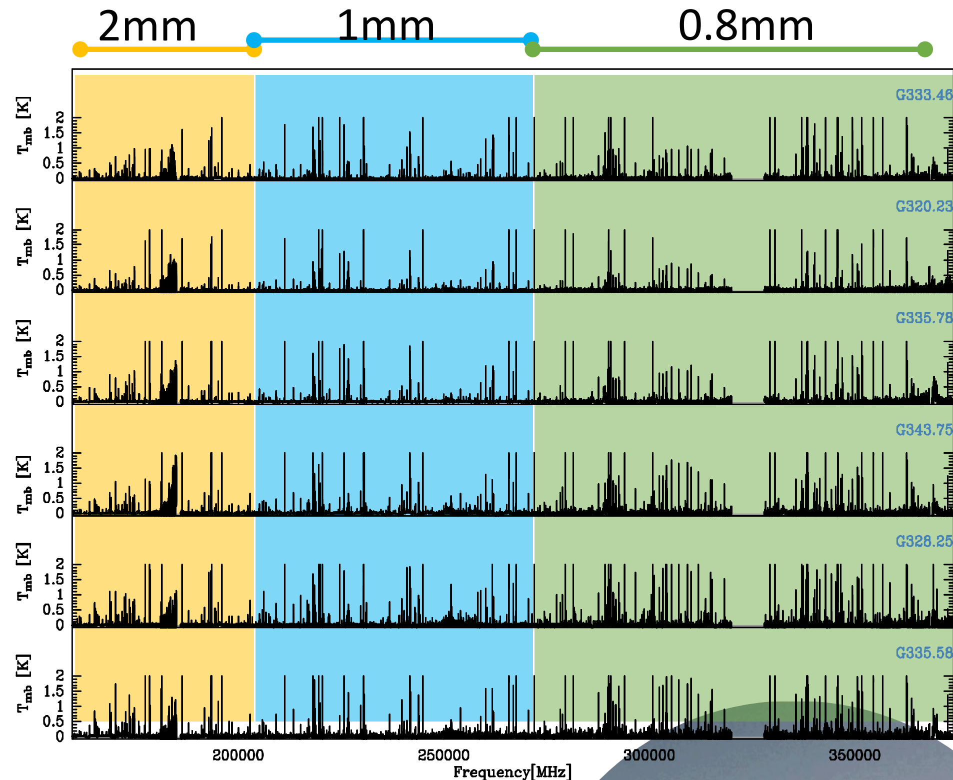
Spectral survey with APEX

Large bandwidth:

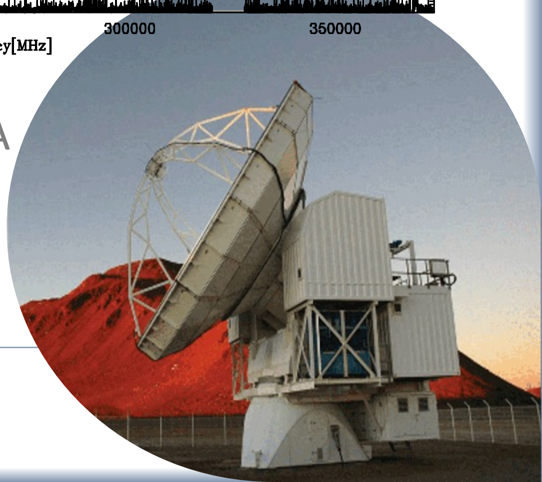
- Several molecules
- Several transitions for each molecule



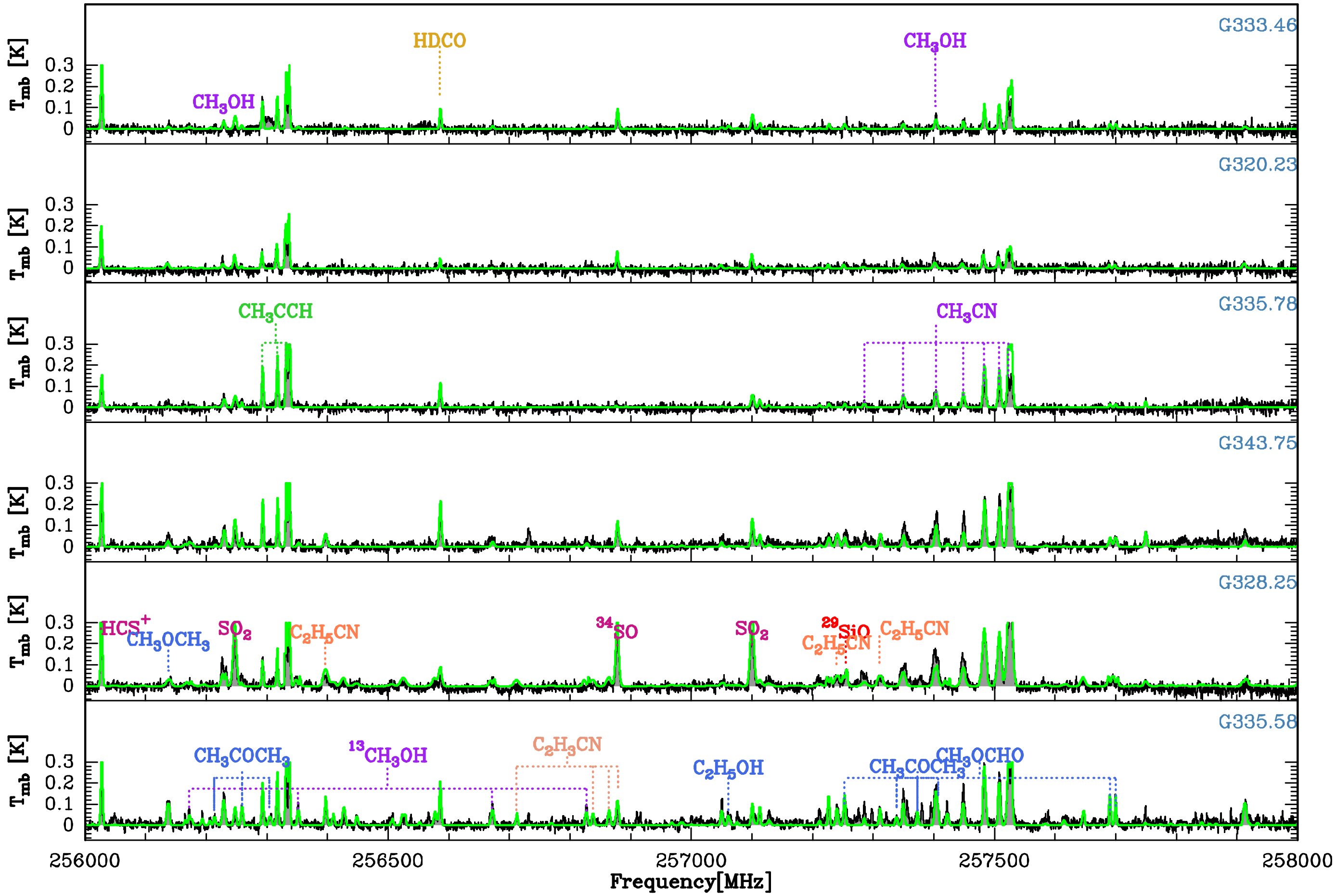
Frequency coverage of the 2 mm, 1 mm and 0.8 mm bands with APEX overlaid by the atmospheric transmission



Bouscasse et al. 2022, A&A
Bouscasse et al. in prep



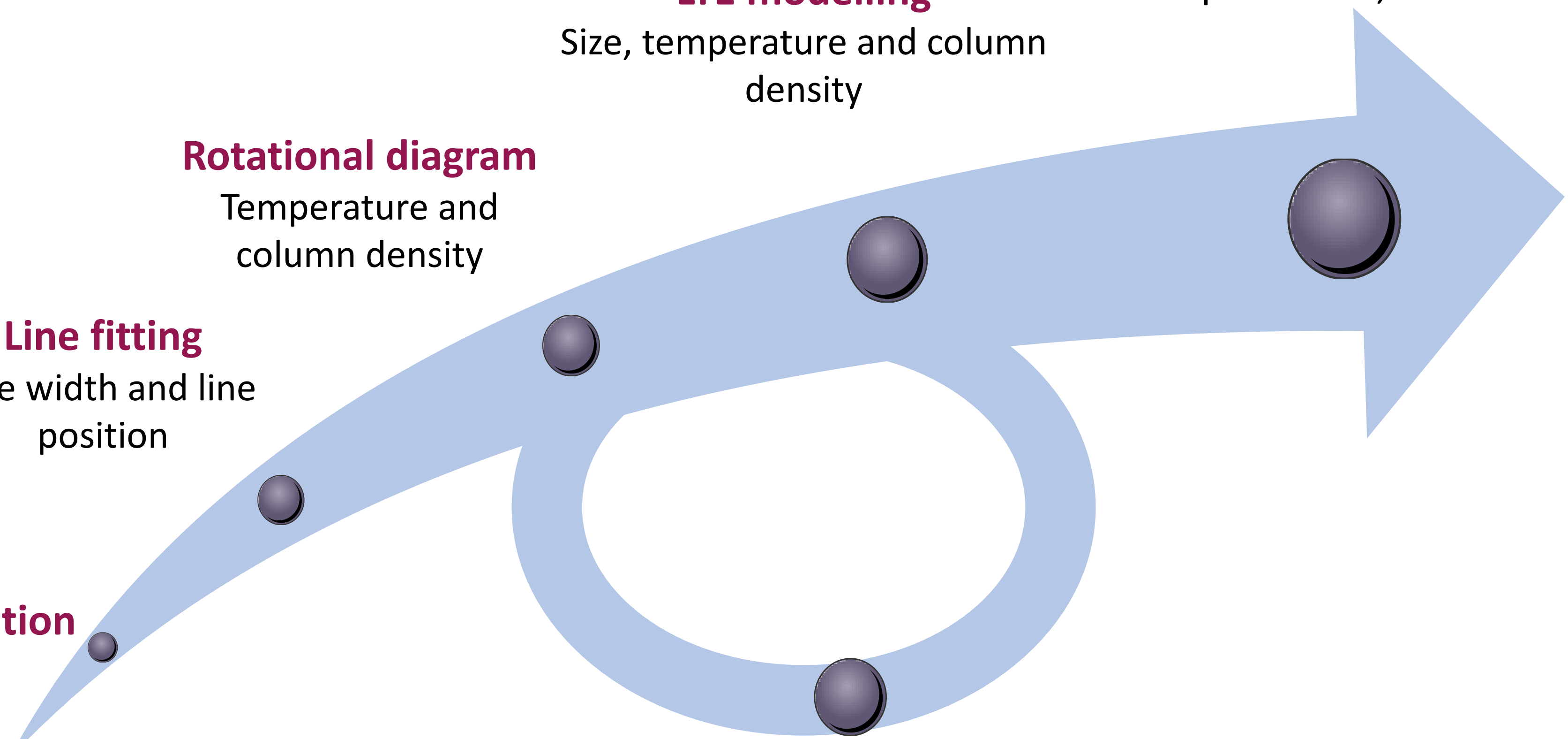
Molecular diversity



Spectral survey of 206 GHz towards 6 objects (Bouscasse et al. in prep)

Line density: 5-26 lines/GHz above 3σ (102lines/GHz above 4σ in Sgr B2, Belloche et al. 2013)

Methodology



Six sources: a molecular diversity?

Carbonated Chains	O-bearing	N-bearing	Deuterated	S-bearing	COMs	Others
CCH	CO	CN	DCN	CS	CH_3OH	SiO
HC_3N	HCO^+	HNC	DCO^+	OCS	CH_3SH	*PN*
CH_3CCH	H_2CO	HCN	HDO	H_2CS	CH_3OCHO	
c-C_3H_2	H_2CCO	NO	HDCO	SO_2	$HC(O)NH_2$	
	HCO	N_2H+	HDCS	SO	CH_3OCH_3	
		CH_2NH	DNC	NS	CH_3CHO	
		HNCO	N_2D^+	H_2S	CH_3COCH_3	
		$HCNH^+$	CCD	HCS^+	C_2H_5OH	
				SO^+	CH_3CN	
				NS^+	C_2H_3CN	
				CCS	C_2H_5CN	

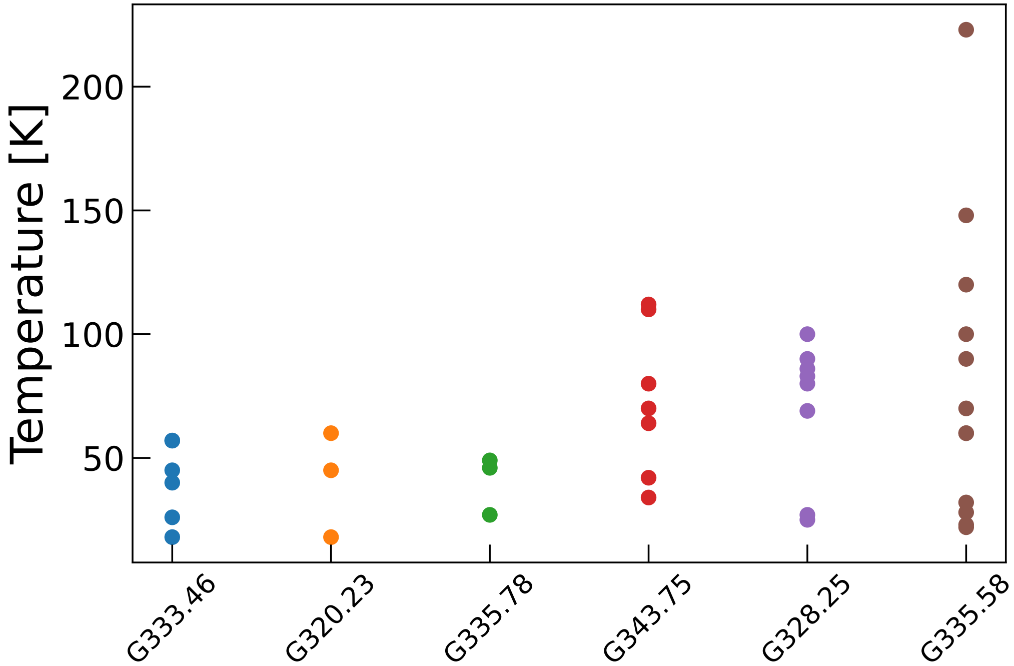
All objects

Differences

Molecular emission varies between the objects.

Largest differences: S-bearing molecules, deuterated molecules, COMs

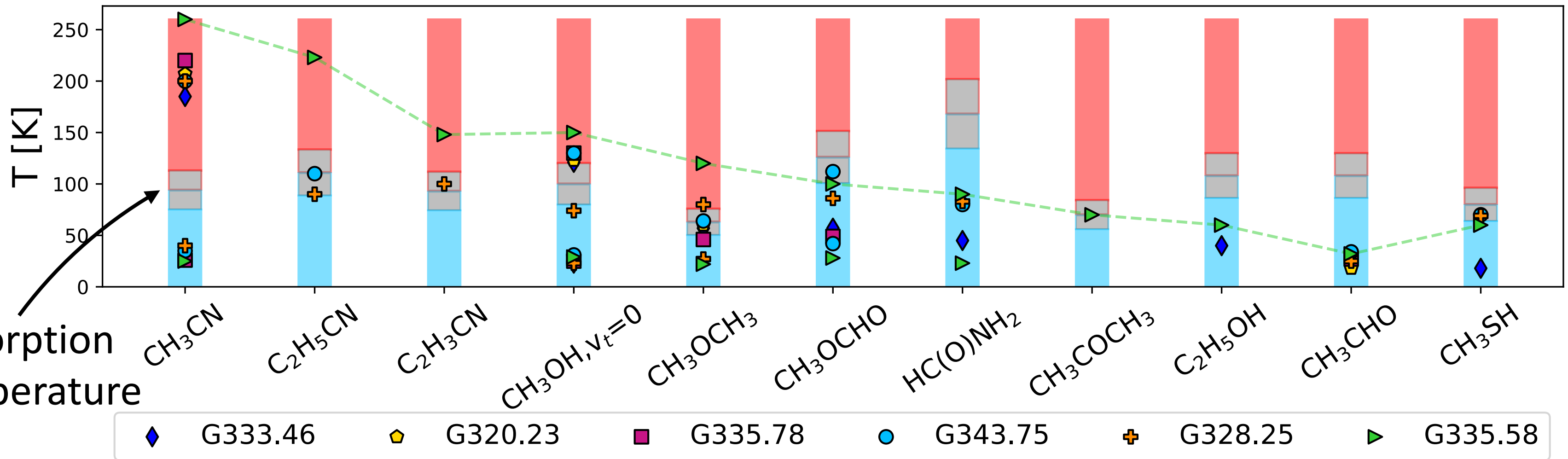
Temperatures in the sample



Temperature of the COMs (except methanol and methyl cyanide) in the objects

- The **bulk of the gas** is still **cold.**
- The warm gas is traced only by CH_3OH, and CH_3CN in 3 objects.
- **3 sources** have a well defined **warm gas phase.**
- **Emergence** of the warm gas phase.

Temperatures in the sample

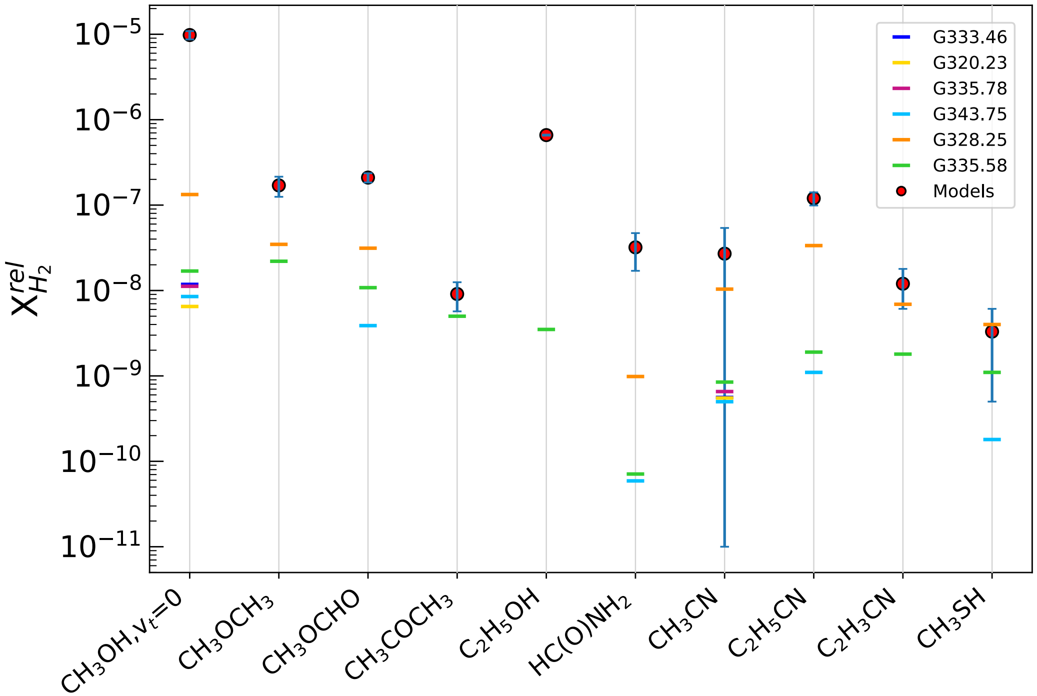


Desorption temperature

T_{ex} for each molecule in each object (Bouscasse et al. in prep)

Thermal desorption	?	Non-thermal desorption
CH_3CN	CH_3OH	CH_3COCH_3
C_2H_5CN	CH_3OCH_3	C_2H_5OH
C_2H_3CN	CH_3OCHO	CH_3CHO
	$HC(O)NH_2$	CH_3SH

Warm gas: comparison with models

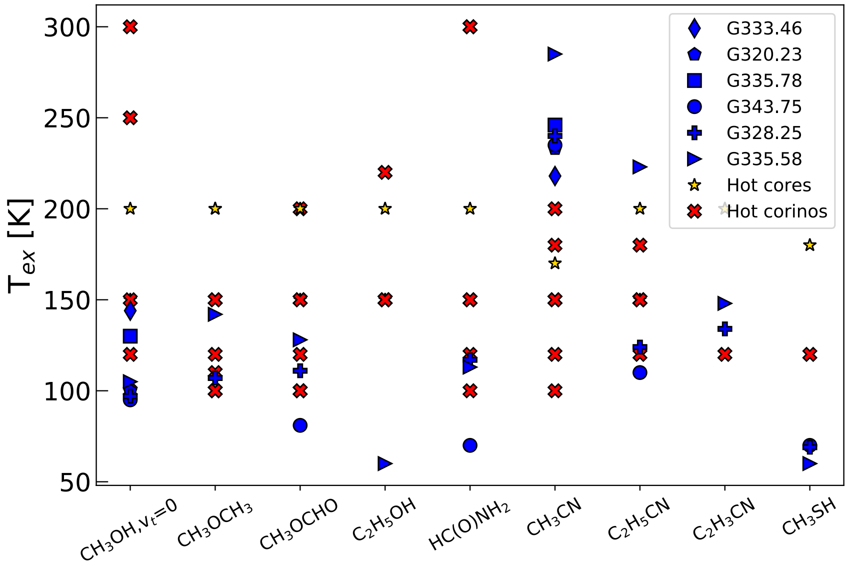


Comparison of the observed abundances with the peak abundances modeled by Garrod et al. 2022.
(Bouscasse et al. in prep)

CH_3CN C_2H_5CN C_2H_3CN	Thermal desorption
CH_3OH CH_3OCH_3 CH_3OCHO $HC(O)NH_2$	?
CH_3COCH_3 C_2H_5OH CH_3CHO CH_3SH	Non-thermal desorption

Warm gas: physical parameters

Temperature



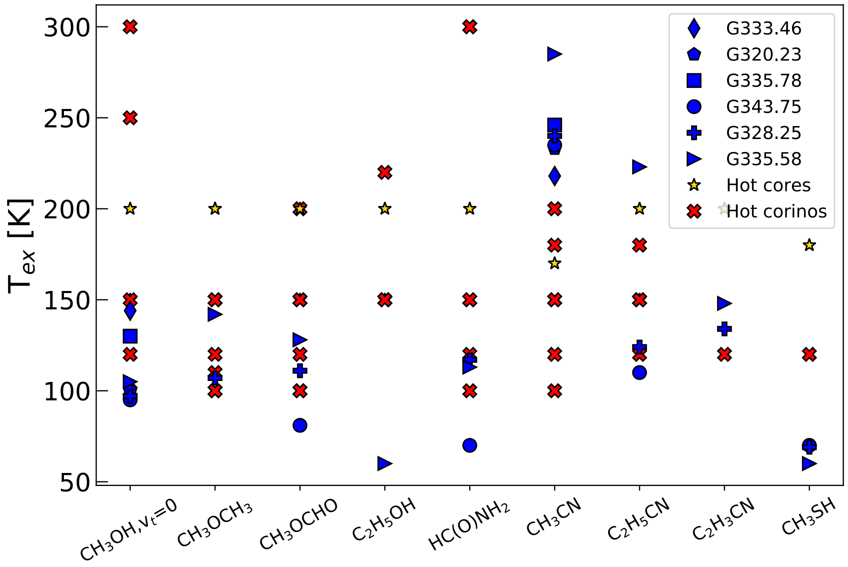
Excitation temperature for all the molecules

(Hot cores: Belloche et al. 2016, Rolffs et al. 2011, Hot corinos: Belloche et al. 2020)

Temperature: similar to hot corinos

Warm gas: physical parameters

Temperature



Excitation temperature for all the molecules

(Hot cores: Belloche et al. 2016, Rolffs et al. 2011, Hot corinos: Belloche et al. 2020)

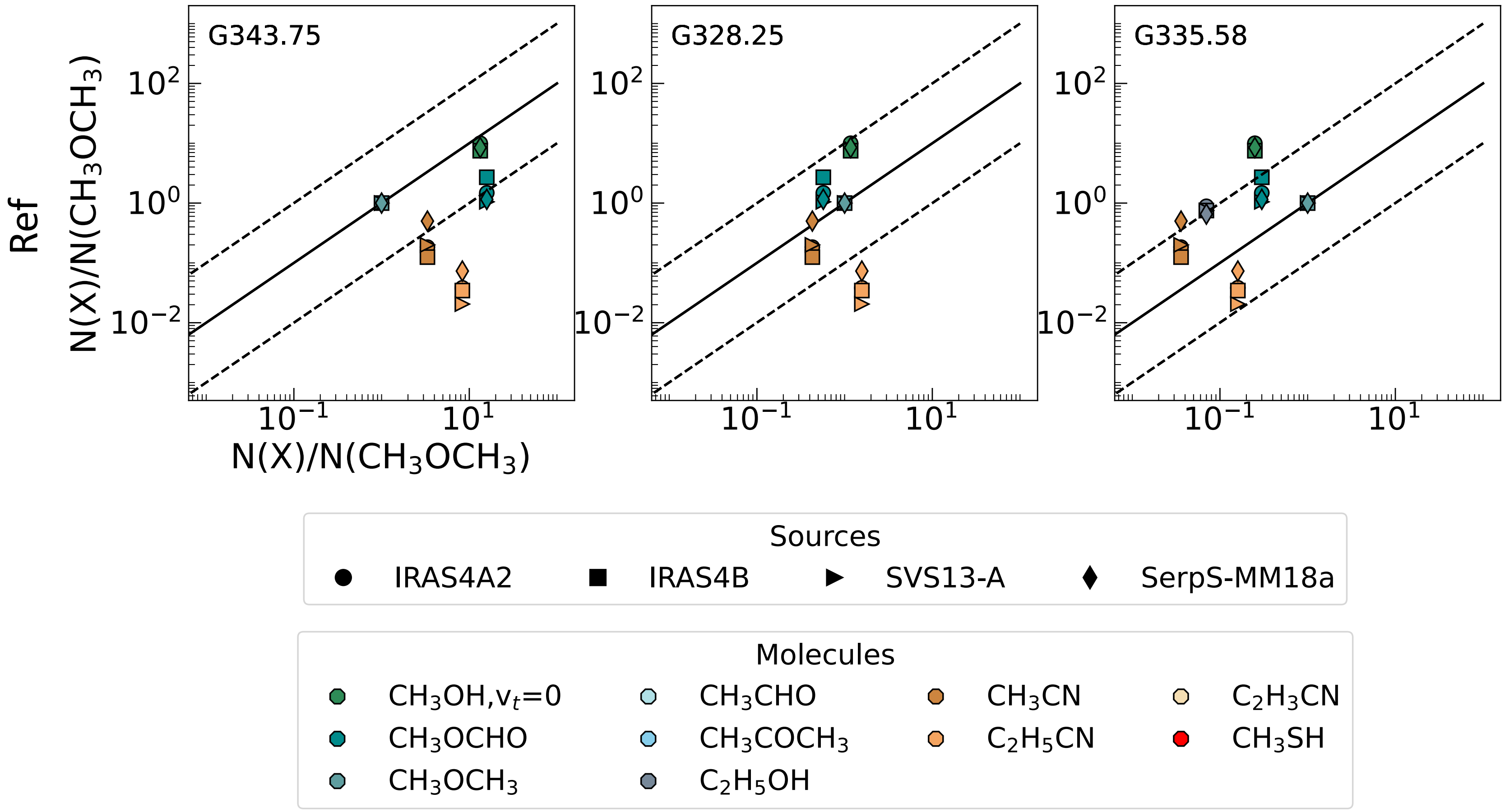
Sizes

- Our objects: 0.05pc
- Hot cores: 3000-5000au (Kurtz et al. 2000, Cesaroni et al. 2011)
- Hot corinos: 100-300 au (e.g. Bianchi et al. 2020, Belloche et al. 2020)

Temperature: similar to hot corinos

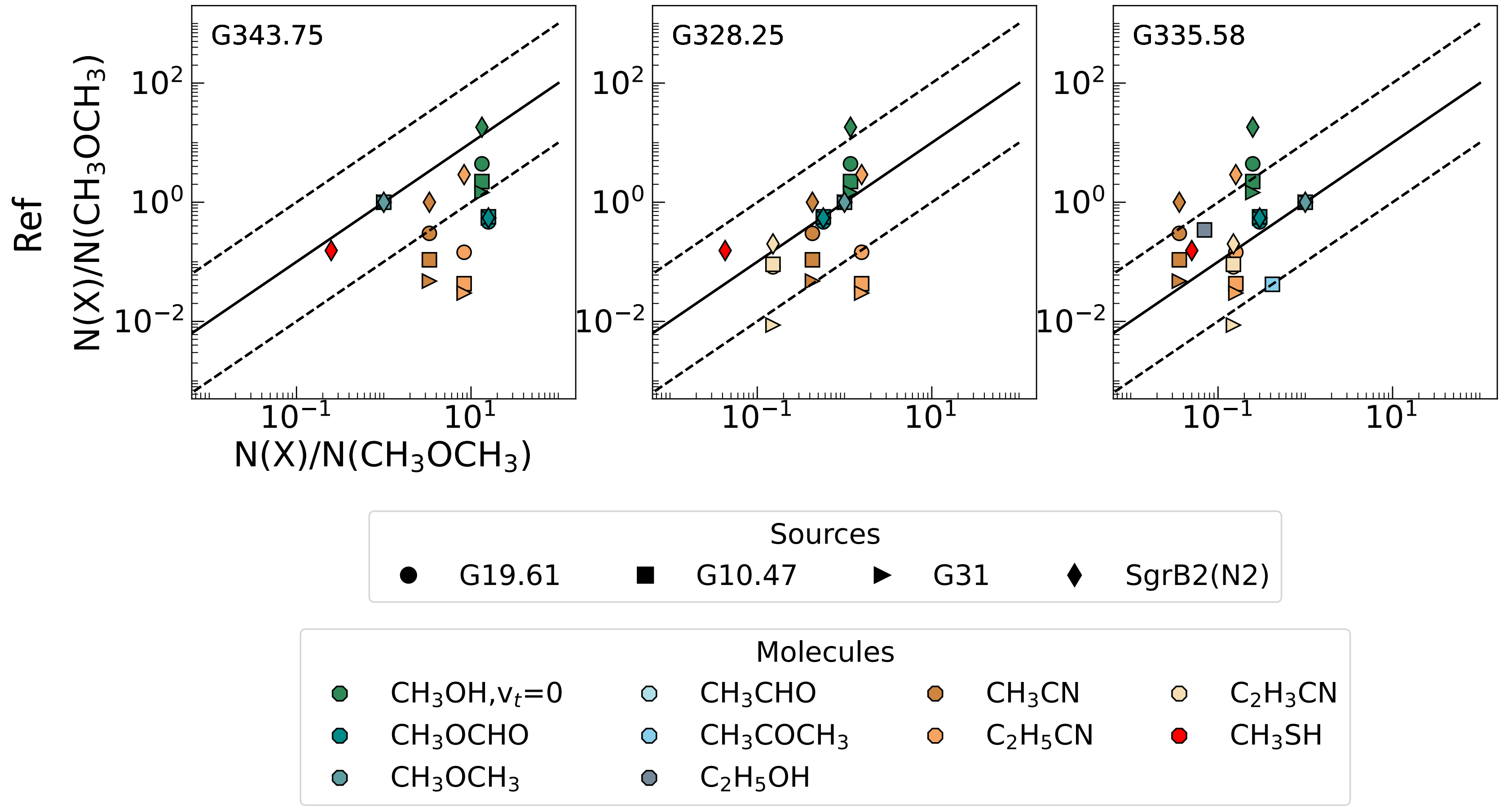
Size: similar to (compact) hot cores

Warm gas: hot corino-like?



Relative abundances with dimethyl ether versus the ones from hot corinos (Belloche et al. 2020)

Warm gas: hot core-like?



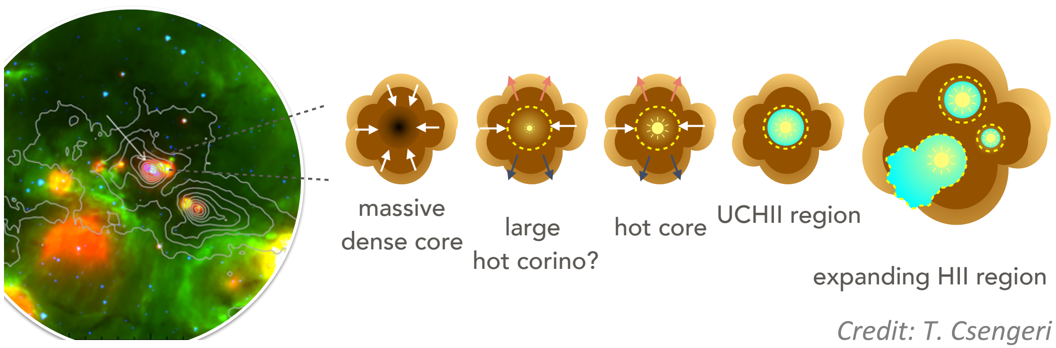
Relative abundances with dimethyl ether versus the ones from hot cores (Widicus Weaver et al. 2017, Jorgensen et al. 2020)

Conclusions

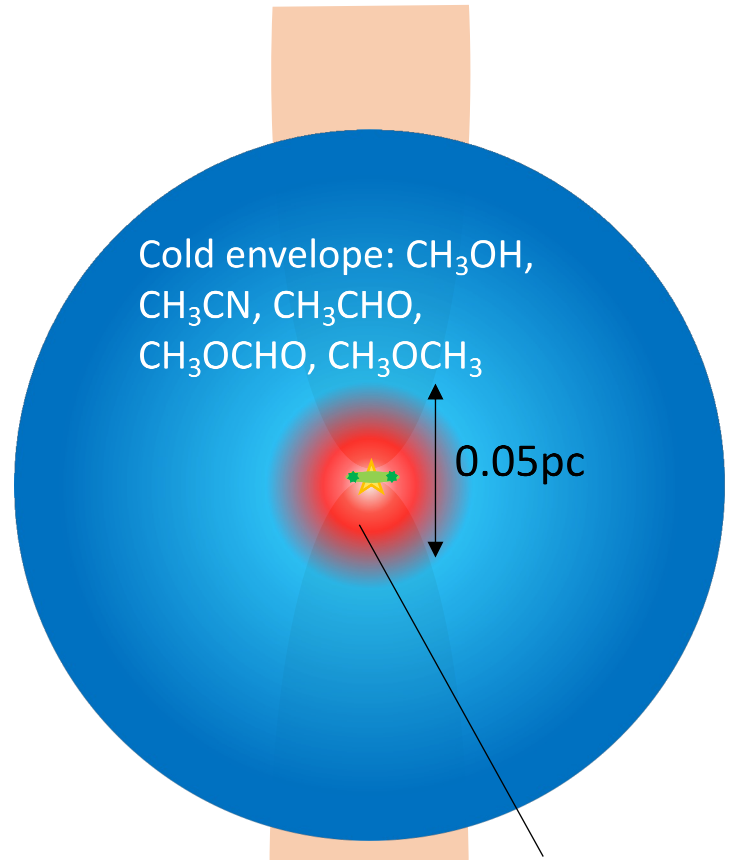
Emergence of a warm gas phase *(Bouscasse et al. 2022 and in prep)*

- Most of the gas is still cold
- COMs does not necesseraly desorb through thermal processes

Hot core precursors = embbeded hot corinos with a larger size



Credit: T. Csengeri



Bouscasse et al. 2022, A&A, 632
Bouscasse et al. in prep, A&A